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The Effects of Sediment and Nutrient Loading on Aquatic Organisms in Nails and Ellejoy Creeks, Blount County, Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Susanna Hannah Sutherland entitled "The Effects of Sediment and Nutrient Loading on Aquatic Organisms in Nails and Ellejoy Creeks, Blount County, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

Joanne Logan, Major Professor

We have read this thesis and recommend its acceptance:

Forbes R. Walker, James A. Drake

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Accepted for the Council:

Vice Chancellor and Dean of Graduate Studies

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Susanna Hannah Sutherland
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ABSTRACT

The health of an entire ecosystem is influenced by its water supply. Nonpoint source pollution, such as sediments and nutrients, cause impairment of water quality and harm aquatic diversity. This study was designed to assess the impacts of excess sediment and nutrients on aquatic health in the Nails (HUC12, 060102010105) and Ellejoy (HUC 12, 060102010104) Creeks, subwatersheds of the Little River (HUC10, 0601020101) watershed and the Watts Bar Lake watershed (HUC8, 06010201) in Blount County, Tennessee. Previous research has shown a negative correlation between these pollutants and benthic indicator species. In 2002, the 303(d) list indicated that both streams were partially supporting. There have been no studies of these streams since 1998, which categorized them as impaired water bodies. A total of 12 sites were sampled 12 times, beginning in June of 2003 and continuing through February of 2004. Parameters tested included Total Kjedahl Nitrogen (TKN), total phosphorous (TP), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), soluble reactive phosphorous), total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), turbidity, biochemical oxygen demand (BOD-5 day), total organic content (TOC), and ammonium (NH3-N). Benthic macroinvertebrates data were collected in August of 2003 and added to available benthic data for these streams from previous years. General Linear Mean procedure was performed on all water quality data. The individual streams showed small positive correlations between TSS, TDS, TS, TKN, NO_3^-, NH3-N, TP, and PO_4^{3-}. A mean separation test was performed to look for differences among sites. Two tributaries on Ellejoy Creek exhibited nitrate differences ($P<0.05$). The lesser nitrate contributor (1.71 mg/L) was surrounded by forest, and the greater one (4.05 mg/L) was agricultural. Benthic macroinvertebrates showed more diversity than anticipated, attributed to the cool, wet conditions of the season. All 3 sites on Nails Creek, and 3 of the 5 sites sampled on Ellejoy were classified by use of the TN State metric system as fully supporting, the remaining 2 being partially supporting. However, Principle Component Analyses of all samples across all sites showed separation between the prolific nutrient tolerant and the few nutrient intolerant species, indicating that high NO_3^- levels are influencing low species diversity. They also showed correlations between poor bank conditions and poor benthic habitat, indicating that aquatic life is influenced by landuse. Both streams will remain on

the 303(d) list, though some tributaries on Ellejoy will likely be removed. Data from this study will contribute to the eventual development of Total Maximum Daily Loads for both streams.

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Introduction and Objectives

The focus of this study was to address the problem of poor water quality due to nonpoint source pollution and agricultural influences in the Nails and Ellejoy Creeks, Blount County, TN. The goal was identification of the influences of nonpoint source pollution on aquatic life and habitat in order to make recommendations to improve the overall environmental quality for the Upper Tennessee River Basin located in Blount County, Tennessee. The specific objective of this study is to effectively assess the impact of sediment loading and nutrients on aquatic organisms in the Nails and Ellejoy Creeks in this area of Tennessee. The study had two components: a field and lab component sampling and analyzing water quality and benthic macroinvertebrates as indicator species to establish a correlation between the two, and a modeling component using the simulation model AQUATOX, which was used to predict and understand possible outcomes of a given ecological scenario between organic pollution inputs and aquatic life. I hypothesized that high sediment and nutrient inputs in agricultural environments have a negative effect on species diversity and the health of aquatic organisms.

Low species diversity in poor aquatic environments found in agricultural settings may not at first appear problematic, but upon closer inspection it is evident that the health of an entire ecosystem and watershed can be critically damaged by small problem areas (NRCS, 1998). Species diversity can serve as an indicator of overall aquatic health, which in turn indicates environmental quality in the watershed as a whole (Barbour et al., 1999). Benthic macroinvertebrates are often used as indicators of aquatic health due to their quick response to environmental changes. Low species diversity of benthic creatures is a good indication that there is low diversity among larger species, which is a good indication that the water supply to that particular environment is impaired in some capacity. Low species diversity within a watershed can mean that more rigorous monitoring should occur to pinpoint sources of pollution.

The U.S. Geological Survey identified 54 watersheds in Tennessee that drain into a river or reservoir, around which the Division of Water Pollution Control bases its assessments (Woodside and Hoos, 2001). According to the new 303(d) list proposed for Tennessee in September of 2002 (TDEC, 2002d), hundreds of the streams assessed are listed as impaired, many of which are new entries since 1998. This indicates possibly a growing problem and certainly a growing awareness of poor environmental and water quality in Tennessee, which is being addressed by government organizations, but is getting little attention from local landowners contributing to the problem. The hydrologic unit codes (HUC) for the streams are as follows: Nails (HUC12, 060102010105) and Ellejoy (HUC12, 060102010104) Creeks, subwatersheds of the Little River (HUC10, 0601020101) and the Watts Bar Lake (HUC8, 06010201) watersheds (Figure 1), are two such water bodies currently receiving government attention. Along many stream banks such as these in Tennessee's agricultural areas, livestock have full access to the water supply, allowing feces to filter or be deposited directly into the flowing water, making nitrates a strong contributor to high nutrient loads in the watershed (TDEC, 2002d). It is visually evident in the Nails and Ellejoy areas that the sediment load is high due to runoff from pasture grazing and livestock traffic in and out of these streams.

According to Tennessee's Department of Environment and Conservation's proposed September 2002 303(d) list, both the Nails and the Ellejoy creeks are considered to be only partially supporting, meaning that they are somewhat impacted by pollution, they exceed water quality criteria on some frequency, and their overall water quality is considered moderately impacted (TDEC, 2002d). In 1998, Tennessee Valley Authority (TVA) and Tennessee's Department of Environment and Conservation (TDEC) conducted benthic and fish studies on both streams. These studies revealed that both creeks support fish and aquatic life, but only as depressed diversities, and with many of the more pollutant intolerant species missing (Burr, 2002). According to the agreement between TDEC and the U.S. Environmental Protection Agency, the absence of these species is one of the methods used to justify the impairment of these waterbodies, as in Tennessee it is not necessary to have a virtually dead stream before placing it on the 303(d) list (TDEC, 1998).

No further study of either of these creeks has been documented since 1998, and the problem of nonpoint-source pollution in these areas has not yet been addressed. Studies that deal with organic pollutants and their environmental effects will be valuable in drawing recognition to this problem and for developing restoration plans to reduce pollution in this area of the Little River Watershed. Ideally, positive pressure will be placed on the local landowners to implement better land management practices (BMPs).

Chapter 1

Literature Review

A History of Water Quality Studies

A primary goal of the Clean Water Act is to "restore and maintain the chemical, physical and biological integrity of the Nation's waters" (U.S. EPA, 1972). Understanding the relationships between chemical and physical environment and aquatic life is one of the biggest challenges of maintaining good water quality. Historically, studies have revealed that overall water and environmental quality of an entire watershed are greatly affected by the water and environmental quality of the thousands of feeder streams comprising that watershed (Sweeney, 1992). Theory behind this is exemplified in Robin Vannote's "River Continuum Concept," which hypothesizes that functional and structural characteristics of stream communities are adapted to conform to the most probable mean, or tendency, in the physical system (Vannote et al., 1979).

Past studies range from water quality assessments from an ecological standpoint to hydrological studies from a geomorphic standpoint. Biochemistry studies have been designed to look at the watershed chemistry for informational purposes, and to see how upstream inputs affect downstream ecosystems (Stottlemyer, 2001). Studies dealing with sediment and nutrient loads are usually aimed at establishing a loading precedent or improved land management, and grazing management in rangelands with high concentrations of livestock (Nguyen et al., 1998), and do not deal directly with the quality of aquatic life. Studies that examine the quality of aquatic life usually look at all aspects of water quality and do not focus on sediments and nutrients, but incorporate the two with all other contributing factors (Callisto et al., 1998).

Historically, it has been rare for a biological study to combine both biotic and abiotic components such as solids and nutrients with aquatic organisms; in recent years, however, there have been some examples of this. A study conducted in southern New Zealand looked at changes in agricultural intensity and river health along a river continuum. This particular study addressed agricultural activities as a global issue not clearly recognized by landowners or land and water management agencies, and found that high benthic sediment and nutrient levels caused species richness to diminish (Harding et al., 1999). The study also indicated that agricultural intensity and physical conditions associated with agricultural activity were strongly associated with the composition of benthic macroinvertebrates. Many of the studies similar to Harding's have dealt with the relationships between benthic macroinvertebrates, land use, sediment quantity and nutrient loads in the Chesapeake Bay area. Though these studies deal with sediment contaminants and point source nutrient loading as opposed to sediment amounts and non-point source nutrient loading, they do shed light on land use impacts on benthic communities. In the case of urbanization, this study showed a very negative impact (Dauer et al., 2000; Pionke et al., 2000).

Land use has often been the focus of sediment and nutrient studies, and often is a point of contention between environmental groups and landowners. Agriculture and urbanization are most often the subjects of these studies, as they produce high levels of contaminated sediment (Honisch et al., 2002; Lenat and Crawford, 1994). Water quality and aquatic life are sensitive and respond immediately to land use changes, which in the more problematic areas, are continually being reviewed and monitored by environmental agencies for the development of better land management practices.

Nonpoint Source Pollution

As water quality studies have shown repeatedly, sediments and nutrients in excess can create costly and frustrating problems that are difficult to solve. One of the most difficult challenges we are faced with when trying to maintain or restore good water quality are nonpoint source pollutants such as these. Nonpoint source pollutants may be defined as an introduction of impurities into surface and groundwater supplies from diffuse, non-direct, or intermittent sources such as excess storm water, snowmelts, road runoff, agricultural field leachate, construction site erosion, mining, logging, and precipitates from air bourn pollution (Mulligan, 1996). Studies have been conducted to better understand the dynamic of nonpoint source pollution (Schreiber et al., 2001), and information is available from the U. S. EPA the kinds of nonpoint problems found on a state-to-state basis (U.S. EPA, 2004a). According to a fact sheet created by the University of Ohio, most non-point source pollutants fall under six categories: sediments, nutrients, acids, heavy metals, toxic chemicals, and pathogens (University of Ohio, Athens, 1992). Stated in this document were the sources, effects, and definitions of these six, summarized in the following paragraph.

Sediments are considered inert particles of sand and other fine, coarse ground particles carried downstream during high flows and deposited at lower flow points. In excess, they cause damage to filter feeders, clog gills, impede movement, reduce the ability of light to filter to stream bottoms, and slow movement through spawning gravel. Sources include construction sites, mining, logging, agricultural activity, stream and shore erosion, and off-road vehicle use. Nutrients include fertilizers, fossil fuels, manure, and organic matter. They contribute to the excessive growth of weeds, algal blooms, bacteria slimes, and plankton. Sources include nurseries, agricultural activities, lawns, gardens, fuel storage facilities, landfills, and heavily vegetated streams and landfills. Acids affect pH through their salt content, disrupting the ionic balance of water, thus eliminating species though chemical and physical reactions. Sources of acid include mining, irrigation runoff, landfill leachate, and road runoff. Heavy metals, including copper, mercury, lead, zinc, tin, nickel, chromium, cadmium, arsenic, and silver, are toxic to organisms in high concentrations and can poison enzyme systems. Sources include mining operations, vehicle emissions, landfills, urban areas, and road runoff. Toxic chemicals include organic and inorganic pesticides, herbicides, insecticides, rodent poisons, and any chemical designed to rid of a pestilence in undetermined concentrations. They come from populated areas and farming operations, nurseries, orchards, and landfills. Finally, pathogens include viruses, bacteria, and protozoa. Sources include livestock operations, wildlife and pet activity, malfunctioning septic systems, and landfills.

Nutrients and Sediments

Nutrients and sediments are some of the most common and frustrating nonpoint source pollutants. As prevention is the best cure, it is beneficial to understand how they are introduced into watershed systems, how they function within the system, and how to remove them once present (Schreiber et al., 1996). In 1994, the U.S. Geological Survey began an investigation of water quality conditions in the upper Tennessee River Basin, with 64% primarily forested area and 27% agricultural landuse. The study looked at sources, trends, and distributions of nitrogen concentrations and concluded that agriculture and wastewater facilities contributed to the highest amount of nitrogen concentrations (Treece and Johnson, 1997). Another study in China found that wastewater discharge and nitrogenous fertilizer additions contributed to the high nutrient concentrations in the Yellow River basin (Xinghui et al., 2002). Sources of nitrogen and phosphates are usually nonpoint source pollution, but can be point source when there is a pipe emitting discharge from a wastewater facility or large storm water systems. Surface water movement dissolves nutrients from soil minerals, crop residues, manures, fertilizers, and other materials, resulting in nutrients moving within the water cycle (Vitosh and Jacobs, 1996).

Nitrogen can be found in the environment in a variety of forms. Ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2) are the most commonly tested, though there are various organic forms of nitrogen, as well as dissolved molecular nitrogen (N_2). Undergoing chemical and biological transformations within a waters system allows nitrogen to be reduced into organic forms that are converted by soil bacteria into nitrate and nitrite, which can then be used by plants (Cole, 1979). Within fresh surface waters, nitrogen is found as NO_3^-, ammonium (NH_4^+), and organic nitrogen. Nitrogen comes from atmospheric deposition and decomposition of organic matter, and is fixed by lightning and dissolved in precipitation. The amount of nitrogen introduced via lightning or precipitation into an ecosystem varies according to geographic location, and can range from 1 to 20 kilograms per hectare. Five to eight kilograms per hectare is a typical amount for temperate ecosystems (Beetz, 2002).

Once introduced into a physical system, nitrogen is fixed in a biochemical process that combines elemental nitrogen into organic forms by metabolic processes, carried out by bacteria, fungi, and cyanobacteria, or blue-green algae. Over 13,000 species of legumes and rhizobium bacteria provide the major biological source of fixed nitrogen in agricultural soils (Pidwirny, 1999). The bacteria invade root hairs of a host plant and introduce the formation of nodules that house the organisms while supplying the plant with fixed nitrogen compounds, and the host plant supplies the bacteria with carbohydrates. While some of the bacteria go directly to the plant, a portion of it passes from the plant roots and nodules into the soil, where it is mineralized to become available for nitrate and ammonium compounds. A portion of the fixed nitrogen also becomes a part of the soil's decayed organic matter. Some non-legumes have been known to develop nodules to house bacteria for nitrogen fixation, and some non-legumes produce no nodules at all. Nitrogen can also be introduced into a system by immigration of organisms that either shed their tissue or die there. Nitrogen leaves ecosystems by soil erosion, surface water leaching, gaseous emissions from the soil in anaerobic conditions, and emigration and harvesting of animals and organisms.

Phosphorous, a nonmetallic element, is important because it is one of the key elements necessary for the development of plants and animals. Toxic in its natural form, phosphorous is capable of accumulation within the environment. Phosphates are chemical compounds containing phosphorus, and they exist in three forms: orthophosphate, metaphosphate, and organic phosphate. Natural processes produce ortho forms. Poly forms are used in detergents, and change into the ortho form in water. Organic phosphates exist in solutions, in the bodies of aquatic organisms, as particles, and as loose fragments.

Phosphates have several methods for entering a water system. Flowing water removes small amounts of inorganic phosphates from rocks, which are taken in by plants with water as nutrients, and incorporated into organic phosphate compounds. Rainfall can also cause phosphates to wash from farm soils into nearby waterways; soils are a good medium for phosphates as well as nitrates, though phosphates travel less quickly than nitrates due to their ability to settle and absorb into sediments, which makes them temporarily unavailable. Phosphates can enter waterways through manmade sources as well, for example: human waste, agricultural runoff from crops, sewage from animal feedlots, pulp and paper factories, vegetable and fruit processing, chemical and fertilizer manufacturing, and detergents.

Most surface waters have a phosphorus concentration of 0.02 parts per million (ppm), which is considered a limiting factor for plant growth (Laws, 1993). However, larger concentrations of this nutrient, when imputed into aerobic, or oxygenated, conditions, can accelerate plant and animal growth and make greater demands on the oxygen supply within a body of water. If phosphates continually enter an aquatic system in large amounts, it can lead to eutrophication, or over fertilization, of receiving waters. Rapid growth of plants and animals within the system will put very high demands on the oxygen supply, causing the potential for large fluctuations in water quality within the system. If large amounts of phosphates are entering anaerobic conditions, or systems lacking oxygen, bacteria attempting to decompose the excess organic matter may use up all available oxygen. Reactions continue, but the results are different. Carbon is converted to methane gas instead of carbon dioxide, and sulfur is converted to hydrogen sulfide gas, or precipitated as iron sulfide. Because of these imbalances, the system potentially could become a swamp, as the water body fills with partially decayed organic matter (U.S. EPA, 2004b).

As with any system, large inputs or outputs will imbalance the entire cycle. Grazing livestock greatly effects nutrient cycles by imputing abnormally large amounts of nutrients into the system. Only a small proportion of fixed nutrients are ingested and used for growth; the rest are excreted in feces and urine. Livestock urine contains a high amount of nitrogen and potassium, and their feces contain a high amount of unused phosphorous, as well as nitrogen and potassium if the feed is supplemented with it. Liquid forms of these nutrients can go straight to the roots, or be flushed into nearby waterways in pasture runoff (Allison, 1968).

Many studies have been devoted to examining how these excess nutrients affect nearby waterbodies. One such study found that stream systems near a wastewater treatment plant showed that high nutrient loads affected aquatic ecosystem interactions, showing that the natural ability of a stream system is severely limited when dealing with unnaturally high nutrient levels (Marti et al., 2004). Other studies have looked at managing material transfer and nutrient flow in agricultural watersheds, approaching watershed management from the individual ecosystem specifics of a stream (Nord and Lanyon, 2003, Franklin et al., 2002), and some have studied the ability of soils to absorb nitrates and phosphates (Griffin et al., 2003, Hiroko and Tsuruta, 2003). Flooding and high flow events have also been studies to see how nutrient mobility is influenced in manure-impacted soil, finding that the preestablishment of riparian communities, or fauna lining the stream bank, could alleviate nutrient influxes into agricultural waterways (Pant et al., 2002). A few studies have measured the removal of pollutants in restored wetlands with highly variable inflows, though one such study found that while the variability of inflow decreased wetland removal capacity, overall there was substantial removal of non-point source pollution (Jordan et al., 2003).

Nutrients find a transportation medium in sediments, which is why sediments cannot be ignored in a water quality study (Matisoff and Eacker, 1992). Researchers and managers need to understand sediment transport to be better able to predict how landuse will alter erosion rates, the importance of different sediment sources, where it will be deposited, stored, and when it will move again. Sediment budgets aid in determining these factors, and are convenient if there are time and resources for data collection and analysis. A sediment budget is an accounting of the sources and disposition of sediment as it travels from origin to exit in a drainage basin (Reid and Dunne, 1996). It accounts for rates and processes of erosion and sediment transport on hills and in channels, for storage of sediment in bars and other sites, and for weathering and breakdown of sediments in transport or storage (Dunne and Leopold, 1978). For practical application, some combination of the following is needed: the type and location of the major natural and management-related sources of sediment, the approximate amount of sediment from each source type, the grain size distribution of sediment from each source, the approximate volume and grain sizes of sediment in storage along streams, and the approximate transport rate of sediment through stream channels and valley floors (Reid and Dunne, 1996).

The answers to how landuse will alter erosion rates, the importance of different sediment sources, where it will be deposited, stored, and when it will move again are often adequate, but while the budget produces much of the information collected by monitoring, it does not replace monitoring. Budget construction requires identification of erosion processes, controls, and rates, in order to accurately allot sediment amounts (Stocking, 1987). Steps to constructing a budget include defining the problem, acquiring background information, dividing the area, interpreting aerial photographs, conducting fieldwork, analyzing it, and checking the results. Studies have been done to caution researchers on the unmeasured residuals in sediment budgets (Kondolf, 1991), and these, like models, have gray areas. Nevertheless, they can serve as a starting point to understanding what flows through an aquatic system, where it will settle, and when it will move again.

Not only can large amounts of nutrients move with large amount of sediments, but an unnatural amount of sediments and nutrients can also be very harmful for aquatic life, clogging gills and hampering oxygen intake. A study in the Nashville Basin, TN, conducted by TDEC, revealed that there was a measurable relationship between benthic species diversity and nitrate loading (Arwine, 2004). Multiple studies conducted in New Zealand have found that benthic macroinvertebrates diversity and sediment loads are highly correlated, indicating that benthic creatures are very sensitive to sediment loading, and respond differently to both landuse and different sizes of sediment (Holomuzki and Biggs, 2003; Melo et al., 2003, Roy et al., 2003). With increased sediment comes increased turbidity, which clouds the water and blocks sunlight, cutting off a necessary element of photosynthesis for plants, and lowering the water temperature. This last effect can result in a change of species dynamics, even if the change is only a few degrees. Because sediment can drastically alter aquatic ecosystems, studying ways to prevent and reduce this problem is very important.

Best Management Practices (BMPs)

There are no absolute answers to the problem of high sediment and nutrient levels; rather, the best answers are tailored to a specific watershed. BMPs are land management standards that have been agreed upon as environmentally acceptable and are continually being developed and studied for effectiveness, long-term benefits, and problems (Meals, 1996). They are guidelines that are intended to provide cost effective and common sense alternatives to causing extensive harm to aquatic and terrestrial environments in developed and agricultural settings, and to provide a measure of protection for good water quality with the elimination of non-point source pollutants (Inamadar et al., 2001).

Though there are BMPs delineated for all kinds of practices, such as industry, urban areas, aviation, aquaculture, construction, and shipping areas, agricultural BMPs are of the greatest interest for this study. The basic philosophy behind agricultural BMPs is to conduct daily agricultural activities in an ecologically and economically sound manner. Without economically affordable implementation and cost-share programs, most independent landholders could not engage in productive BMPs (Wossink & Osmond, 2002, Yuan et al., 2002). Without nationwide legislation, there is little incentive to change land management. While a variety of standards exist on a state-to-state basis, there is no single national standard. This is in part due to the need for environmental protection to be based on independent variables, such as climate and precipitation, which are unique to individual areas, and due in part to the lack of ability to enforce such practices on unwilling parties. BMPs are also, according to Mulligan (1996), a moving target with the advance of technology and management practices; legislation is too slow to keep up with the constantly changing situations that arise in BMP development.

In agriculture, acceptable BMPs are available for many aspects of farming and livestock raising: crops, fertilization, irrigation, ditching and draining, fuel and tanks, livestock, dead animals, feed handling, riding rings, manure and compost, pesticides, site selection and layout, soil conservation, water supplies, and organic refuse, to name a few. Stream bank fencing and riparian buffer strips, or the vegetative zone bordering streams, are BMPs that are targeted to reduce suspended sediment and nutrient inputs to streams by reducing direct inputs from animals, aiding in reduction of bank erosion by trampling, and encouraging revegetation of stream banks (Inamadar et al., 2002). Studies have been conducted to observe nitrogen uptake by riparian vegetation (Fennessy & Cronk, 1997), and nutrient retention in holding ponds (Yan et al., 1998). Animal waste BMPs have been proven over and over to be effective in reducing both loads and concentrations of all forms of nutrients (Brannan et al., 2000), and are strongly suggested in agricultural land management. Other studies have identified problems, benefits, and calibration and response times for BMPs in small watersheds (Galeone, 1999; Vought et al., 1995), as well as observed decreases in indicator bacteria counts, sediments, and nutrients, as a result of BMP implementation (Meals, 1996, Inamdar et al., 2002). A study in Wisconsin (Wang et al., 2002) found that the addition of riparian BMPs showed the most pronounced improvements in habitat and water quality, but insisted that high water temperatures did not improve due to lack of BMPs upstream of the study area.

BMP studies have also been completed on the usefulness of remote sensing, GIS, and modeling in analysis of non-point source pollution problems on a watershed level, to aid in identifying sites in need of BMPs and to judge their effectiveness once implemented (Basnyat et al., 2000, Cryer et al., 2001). Though there is evidence that BMPs can be effective in achieving goals of cleaner water and reduced soil loss, they have to be continually maintained to be continually effective. This is a commitment that some landowners are either not able or willing to make.

Total Maximum Daily Loads (TMDLs)

Information regarding the amount of a pollutant in a waterway per year is useful for implementing an appropriate BMP, for monitoring the water in contact with it, and ultimately for deciding its level of effectiveness. Since the Clean Water Act of 1972, there has been confusion regarding standards for pollution levels. In July of 2000, the U.S. EPA issued a final rule to improve the identification of polluted waters, to locate pollution sources, and to commence clean up methods (U.S. EPA, 2000). This program, though since modified, has been cooperating with individual states in an effort to clean up polluted waters in a cost effective manner. The original rule maintained that a TMDL would contain the following: the name, location, and designated use of a waterbody, identification of a pollutant and the water quality standard for the waterbody, the amount of pollutant allowable to meet state standards, the load reduction needed to meet those standards, sources of the pollutant (point and nonpoint), and an implementation plan. Ultimately, TMDLs are a compromise: they calculate the maximum amount of pollutant that a body of water can receive while still meeting the required quality standard set by individual states. Portions of the pollutant are allocated to the pollutants sources, ideally identifying a responsible party (U.S. EPA, 2004c).

TMDLs deal with point and nonpoint source pollution, and attempt to accommodate growth with a small margin of safety. As with any legislation, there has been controversy over point and nonpoint sources under the TMDL rule. Though nonpoint sources of pollution are allocated legal amounts of pollutant on paper, they are ultimately credited to point source polluters in the pollution load allotment, decreasing the amount of pollution a known point source can legally input into the natural system. This is due in part to the inability to locate sources of origination for the nonpoint pollution, and the confusion surrounding who is to be responsible for nonpoint source pollution. Some think that nonpoint, or "blended" waters, should be listed under the 319 NPS program unique to each state. Others, the EPA included, think that the wording in the Clean Water Act pertains to all waters, and that nonpoint polluted waters should be treated the same, under the 303(d) listing of impaired waters. Therefore, new regulations require TMDLs for nonpoint pollutants, such as nutrients and pesticides, and impaired waters of the same must now be listed; many sources previously called nonpoint, such as road and agricultural runoff., are being reassigned as point source pollutants, to take a portion of the load off of point source polluters. Amid controversy and confusion between states, federal government, and private organizations, state environmental agencies are scrambling to develop TMDLs that will not only hold up in a court of law, but also achieve the goal of delisting 303(d) waterbodies and maintaining cleaner waters.

In Tennessee, TMDLs are defined by TDEC as "quantifying the amount of a pollutant in a stream, identifying sources of the pollutant, and recommending regulatory or other actions that may need to be taken in order for the stream to no longer be polluted" (TDEC, 2002a). Tennessee does not establish

TMDL's for all bodies of water, even if they are on the 303(d) list, if BMP's or other applicable actions are being implemented, or the pollution stems from sources in other states. TDEC prioritizes TMDLs on a watershed rotation system spanning a 5-year period. At the end of this time, during which water has been sampled over the course of 2 years, resulting in TMDL development, a watershed plan is published that proposes reasonable cleanup procedures (TDEC, 2002a).

Another example of state TMDL initiative is a study in Lake Okeechobee, Florida, conducted by Florida's environmental department, which tried to develop a total phosphorous concentration goal within the TMDL process. They addressed an imbalance of flora and fauna cause by large algal blooms, by use of a pollution-loading model, and by identifying the occurrence of samples with an excess of chlorophyll (greater than a moderate bloom) as a function of total phosphorous concentrations to specify a total phosphorous goal. When concentrations of phosphorous fell in the appropriate category, the occurrence of large blooms was improbable. The study concluded that successful implementation of the TMDL should significantly reduce the bloom frequencies in the lake (Havens and Walker, 2002). Another study addressed the issue of selenium in waterways, a little looked at contaminant that hinders reproduction in fish and water bird species (Lemly, 2002). A seven-step process was designed to follow the EPA requirements, including load calculation, pollution allocation, and monitoring. Modeling for TMDL development has also been a point of study, estimating parameter uncertainty to create a level of confidence that is workable, and concluding that the need for probabilistic information should be addressed before allowing them to be used in TMDL designs (Bosuk et al., 2002).

Watershed Modeling

Even apart from TMDL development, the use of models is a popular strategy used in watershed and land management. Models are helpful mainly because they aid in forming predictions and correlations between a particular environment and its influences. Pollutant sources vary in time due to changes in weather patterns, population, or economic trends. It is often difficult to compare pollutant loads due to differences in the nature of each pollutant source, and difficult to predict the response of any particular environment and community to these pollutants, due to the complexity and individuality of each ecosystem

(Santhi et al., 2001). While models have limitations, they can increase understanding of natural interactions. For example, NANI (Net Anthropogenic Nitrogen Input), a model that uses water yield and net nitrogen inputs, accounted for 95% of the variation in riverine nitrogen flux in a study relating nitrogen input in the Mississippi river basin to the nitrate flux in the Lower Mississippi river. While the authors conclude that the NANI approach neglects to address several processes in the nitrogen cycle, it focuses on the terms that are estimated with reasonable certainty. (McIsaac et al., 2002).

Ecological communities, their diversity and development, are difficult enough to predict and explain (Samuels and Drake, 1997) without adding the independent variables of land use and pollutants. Models allow the land manager to investigate scenarios and test theories without harming or tampering with the watershed, or allow landowners the ability to plan for sustainability, as in a study that used the DSSAT (Decision Support System for agricultural Transfer) crop model incorporated with the CENTURY SOM-residue (Soil Organic Matter-residue) module, in order to simulate low-input systems and to conduct long term sustainability analyses (Gijsman et. al., 2002). There are many kinds of models that can be used; the U.S. EPA has a model archive for watershed management available online, many of which are also available for free download (http://www.epa.gov/epahome/models.htm.)

However, much like the studies on the topics of sediment, nutrients, and aquatic organisms, these models usually deal with both sediments and nutrient inputs, or with indicator species and overall water quality (Leon et al., 2001). Several simulation models approach combining the two, such as AGNPS (Agricultural Non-Point Source Pollution Model), used for assessing management alternatives in agricultural watersheds (Mostaghimi et al., 1997), and ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation), but do not have the exact parameters necessary for a study of this type. There is a growing need for ecological risk models that incorporate the direct and indirect interactions of toxins and nonpoint source pollutants with aquatic environments, especially in light of the Clean Water Act and all of its requirements.

AQUATOX is a new simulation model for freshwater ecosystems, developed by Richard Park, Jonathan Clough, and Marjorie C. Wellman of Eco Modeling, for the U.S EPA (Park et al., 2004). AQUATOX is one of the few general ecological risk models that represent the effect of toxic chemical and general environmental fate. The model also represents nonpoint source pollutants such as nutrients and sediments, considers trophic levels including fish, benthic macroinvertebrates, planktonic algae, and submerged aquatic vegetation. It has been implemented for lakes, ponds, reservoirs, small rivers, and streams, and can simulate the transfer of biomass and chemicals from one component of the ecosystem to another by simultaneously computing important chemical and biological processes over time. Not only can AQUATOX predict the pattern of chemicals in aquatic ecosystems, but also their direct and indirect effects on the aquatic community and organisms. This indicates that AQUATOX has the potential to draw relationships between the water quality, the physical environment, and aquatic life in any given area. Sediments and nutrients can be entered, and their effects on fish, macroinvertebrates, and plants are simulated.

Modeling, development of TMDLs and BMPs, and studies on water quality and sediment and nutrient levels look good on a national level, but apart from federal and state government agencies such as TDEC, TVA, the U.S. EPA, and the U.S. Geological Survey identifying problem areas, little is being done in Tennessee to deal with the state's water quality problems. Like many other states, local interest and involvement is sparse, land management traditions are strong, and landowners often lack the desire, time, or incentive to improve their land management practices (Potter, 1991). To remedy this, studies must be done that produce results understandable to the public, and often times models are not presented in such a way as to make sense to someone lacking a computer background.

Surface Water Sampling

Water sampling is the thread linking TMDLs, BMPs, and watershed modeling. Without water sampling, there would be no data to develop TMDLs, no way of knowing if instated BMPs were working, and no input data for water modeling. Because it is so fundamental to the way land and water resources are managed, accepted methodology has been developed for national and state levels. Standard operating procedures (SOP) from the U.S. EPA are widely available for all kinds of sampling, but with the disclaimer that sampling situations are widely varied, so no one sampling procedure is recommended. For surface water, there are four listed: Kemmerer bottle, Bacon bomb sampler, Dip sampler, and Direct method.

These techniques are recommended for the collection of representative samples from most surface waters (U.S. EPA, 1994).

The Kemmerer bottle functions like a tube and takes samples at considerable depths. It is good for use off of bridges, boats, and piers, because it is lowered into the water. The Bacon Bomb sampler is for similar situations as the Kemmerer. The dip sampler is useful in situations that provide limited access, such as lagoon banks and discharge pipes, and functions like a scoop to remove water. The direct method is used for steams, rivers, lakes, and other surface waters (U.S. EPA, 1994). It is employed in this study, and consists of removing water from the stream directly in the sample bottle.

There are potential difficulties associated with surface water sampling, including sampling bias if proper procedures are ignored, cross contamination of samples, neglected equipment calibration, and improper collection methods. If equipment is not clean and if the site is somehow disturbed, the numbers obtained from the sampling event can be a misleading representation of the actual body of water. It is important that care is used in sampling, to avoid confusion and uncertainty in the accuracy of the results.

Biomonitoring and Benthic Macroinvertebrates

Creating a reasonable TMDL goes beyond modeling, instating a plan to sample water, and improving the land management practices. An area in question must be monitored for not only the quality of water but also for environmental indicators of disturbance or stability (Montgomery et al., 1995). Biomonitoring is the use of biological responses to assess changes in the environment, and can be quantitative, semiquantitative, or qualitative (U.S. EPA, 2002). Increasingly it is being used in water quality programs of all types, and involves the use of indicator species or communities, such as benthic macroinvertebrates, fish, or algae. As in the Lake Okeechobee study mentioned previously (Havens and Walker, 2002), the presence or absence of an indicator reflects environmental conditions. It is necessary to know which species should be found in the study environment, and which species indicate a problem. Since 1989, bioassessments have been the primary tool for evaluating the biological condition of a waterbody (Southerland and Stribling 1995). These are ecological studies conducted to assess the health of a watershed or waterbody. Techniques and equipment vary within natural resource agencies, but whatever the method, the end results produce data for a region useful in determining problem areas. State agencies are encouraged by the U.S. EPA to incorporate as many methods as possible a bioassessment to get the most comprehensive data possible (USGS, 1997). Often funds and resources are not available for multiple sampling styles and different lab analysis, making this difficult to accomplish.

According to the U.S. EPA, ecological integrity has three components: chemical integrity, physical integrity, and biological integrity. When one of these components is disrupted, the overall health of the waterbody is compromised and the aquatic life present in it will reflect the degradation. (U.S. EPA, 2002). Aquatic life functions around the cumulative effects of different environmental stressors, such as increasing temperature, excess nutrients, heavy sediment loading, and high levels of toxins. While all aquatic life is affected by changes in the chemical and physical makeup of a waterbody, the smallest organisms are naturally the most sensitive (Dauer et al., 2000). Unable to process pollutants as effectively as larger species, they decrease in numbers and sometimes disappear altogether.

Benthic macroinvertebrates are the small creatures, mainly insects in their larval stages, that live in the benthos, or the peripheral area of a body of water. Because benthic macroinvertebrates are small and sensitive to various short-term environmental stressors, they make good indicators of environmental pollutants that may otherwise go unnoticed for longer periods of time (Barbour et al., 1999). There are several advantages to using this particular biological assemblage. During certain life stages they are more susceptible to pollutants, so some will be quickly affected before the entire biological assemblage is affected. They have limited mobility and short life spans that respond quickly to stress. Also, they serve as food sources for fish communities, and healthy fish communities are of interest to both landowners and local and state agencies. Finally, they are not difficult to sample and are usually abundant in most bodies of water. Use of these creatures as an indicator of water quality is not infallible, but they can be used as a quick indicator of severe degradation and extreme conditions.

Macroinvertebrates have traditionally been used in studies that deal with high nutrient loading. One study showed that community structure of small benthic communities could be used to identify primary sources of impact, based on their responses to it (Fletcher et al., 2001). Another showed that reduction of nitrogen in a lake community caused the benthic macroinvertebrate community to increase drastically (Svensson et al., 1999). While macroinvertebrates are fairly sensitive to nutrient loading, some are able to survive in low oxygen, high sediment conditions. These include chironmids, air-breathing snails, mixed diptera species such as larvae, and perhaps Mayfly, Stonefly, and Caddisfly larvae, though these do not tolerate poor conditions very well (Yount and Niemi, 1990).

Sampling styles fall under two categories: the single habitat approach and the multihabitat approach. The single habitat approach involves the 1-meter kick net and is valid because macroinvertebrate density and abundance is usually greater in cobble, or riffle/run habitats (Plafkin et al., 1989). When this substrate is present, it generally gives a good idea of the overall habitat of the stream. When it is not present, alternative habitats should be sampled to provide a suitable understanding of stream reach. The appropriate selection of sampling styles should be based on habitat and physical environment rather than level of impairment. In the single habitat approach, a composite sample is taken from individual sampling spots in riffles and runs representing different velocities, beginning downstream and proceeding upstream. The specimens collected in the kick net from all locations make up a single, homogenous sample. A habitat assessment is conducted also for greater sampling accuracy.

In a multihabitat approach, a D-frame dip net is used to collect specimen from varied habitats. These habitats include cobble substrate, snags, vegetated banks, submerged macrophytes, and sand and fine sediments (Barbour et al., 1999). Cobble substrate is most commonly found in mountain or piedmont streams, while snag can occur anywhere that has woody debris piled up. Vegetated banks are sampled similarly to snag, and are classified as any bank with submerged roots and leafy plants. Submerged macrophytes are seasonal and not very common and involve aquatic plants that grow submerged in deep water. Fine sediment is the least productive habitat and the net should be bumped along the substrate to reduce the amount of debris collected. Sampling protocols for a multihabitat study also include a 100-meter reach, and different habitats are sampled in approximate proportion to the area they cover. The samples collected from all habitats are combined to form a single homogeneous sample. Once again, a habitat assessment is conducted for better sampling accuracy.

According to U.S. EPA standards, benthic macroinvertebrate samples should be processed in a laboratory under controlled conditions (Barbour et al., 1999). Subsampling is often encouraged by employers to reduce the labor-intensive process of sorting, identifying, and keying in benthic species. Subsampling consists of rinsing the entire composite sample followed by even distribution of these across a grid marked pan. Random grids are selected, often with the use of a random numbers table, and the creatures within these grids are used as the subsample. If the subsample is again too large, it can be subsampled from again, with the final specimen preserved in 70% ethanol. It should be noted that some scientists discourage subsampling, maintaining that it diminishes the accuracy and sacrifices the best possible results (Courtemanch, 1996). Taxonomic identification of these specimens can be done to any level of detail, but consistency is key among samples. Identification to the genus and species levels provides more specific information on the environmental qualities of the area, and the level of sensitivities of these organisms to impairments. Identification to family speeds the process and is sufficient in smaller assessments.

Benthic Sampling Metrics

Metrics, or mathematical methods of classifying data, for benthic macroinvertebrates are often used to clarify collected benthic organisms. Most effective are the metrics that show different responses in light of human influences. The multimetric index serves as a practical method for summary and presentation of the data collected over a period of time, with the ultimate goal of understandability for people from all different scopes of work and interests (Shackleford, 1988). Though they are considered ecologically sound, it is recommended that specific metrics be chosen based on a regional basis. Several studies have been conducted on the effectiveness of metrics, and it has been determined in these that calibration and adjustments should be made regionally, and the most effective kinds are richness measures, trophic and dominance metrics, and a functional feeding group (Resh and Jackson, 1993; Kerans and Karr, 1994).

A list of benthic metrics appears in the Benthic Macroinvertebrates Protocols published by the U.S. EPA (1999). The best candidates of benthic metrics are listed by category: Richness, Composition, Tolerance/Intolerance, Feeding, and Habit measures. Richness measures are the number of distinct taxa, and represent the diversity within the sample. This metric usually consists of species level identification but can be evaluated by genera, families, orders, and other trophic levels. Number of taxa measures the variety of the assemblage, and shows a correlation between the number of species and the health of the environment (Resh et al., 1995). Subheadings of total species richness accentuate key species in the group, and a variety of taxa in this category indicate that the environment is capable of supporting multiple species.

Identity, key taxa, and relative abundance can characterize composition measures. Identity is knowledge about the species and their environmental requirements. Key taxa are those species that indicate something unique about the habitat, and relative abundance is related to both identity and sensitivity. Composition measures provide information on the assembly make-up, from them it can be determined if exotic species are present, and they can compare total populations to total fauna (Plafkin et al., 1989). Relative abundance is used more often than absolute abundance because the relative contribution of individuals to the fauna can reveal more about the relationships between taxa than just population data. The concept behind this is that a healthy assemblage will be consistent within its proportional representation, though individual populations vary. Percentage of the major taxon is a measure of redundancy; a high level of redundancy in the major taxon assumes that it is pollution tolerant (Plafkin et al., 1989). Some diversity indices that measure both richness and evenness in their formulas may function as metrics in some cases but are usually redundant with taxa richness and percent dominance.

Tolerance and Intolerance measures are representative of relative sensitivity to disturbance and can include both pollution tolerant and intolerant taxa. Tolerance is usually not case specific, but some of these metrics can deal with specific organic pollutants, sediment loading, and the sum of intolerant species. These metrics can be independent of taxa or tailored to taxa that are usually sensitive to pollution (Hilsenhoff, 1987). Feeding measures provide information on the balance of food acquisition and morphology. Examples involve the feeding preferences of scrapers, shredders, gatherers, filterers, and predators. Trophic dynamics, or food types, are also included here, as is the relative abundance of carnivores, omnivores, herbivores, and detritivores. Feeding measures show any imbalance in food dynamics, and stresses conditions will be reflected. Trophic metrics are substitutions of complex processes such as interaction, production, and food source availability (Karr et al., 1986). Specialized feeders such as scrapers, piercers, and shredders, are more pollution sensitive and respond more quickly to loss of food types. The reliability of these metrics is poor, due to difficulties with the proper assignment of taxa to feeding categories (Karr and Chu, 1997).

Habit measures outline the mode of existence among benthic macroinvertebrates. Morphological adaptation among these creatures shows the functions for existence and movement in the aquatic environment (Merritt et al., 1996). Habitat categories include movement and positioning mechanisms such as skaters, clingers, divers, swimmers, climbers, and burrowers. Aquatic insect habitat is the primary category used in these measures. Habitat measures are more robust than measures of functional feeding groups in some cases (Fore et al., 1996).

As demonstrated in benthic metrics, macroinvertebrates can be classified according to habitat, feeding style, pollution sensitivities, and behavior characteristics. The single habitat approach to bioassessment sampling, which usually focuses on cobble substrate with riffles and runs, is the method most similar to what was necessary for benthic sampling at the Nails and Ellejoy sites in this study. Details on the execution of this method can be found in Chapter Two.

Chapter 2

Methods

Methodology for this study included water and benthic sampling, and laboratory analysis for Nails and Ellejoy Creeks. Analysis included use of statistical computer programs and the water quality model Aquatox to explore possible changes in water quality and aquatic life in the event of land use changes.

Site Selection

Sampling areas were chosen based on TDEC's TMDL program, which monitors EPA listed impaired stream waters on a four-year rotation. In 2002, Nails and Ellejoy Creeks were scheduled for monitoring, as they were both 303(d) listed in 2000 as partially supporting subwatersheds within the Little River Watershed. Each creek is a fair representation of the kinds of waterways within the Blount County region, mostly agricultural and residential.

Individual sample sites included eight stations on Ellejoy Creek, and four on smaller Nails Creek, chosen by Jonathon Burr from Water Pollution Control, TDEC. Sample sites were selected in relation to possible pollution sources, or upstream and downstream of major confluences, where larger tributaries meet mainstream waters. Sites were spaced as evenly apart as possible to insure accurate monitoring of each stream. GPS coordinates were established for each site upon their approval from TDEC and permission from the landholders.

Watershed Landuse & Site Descriptions

The Little River Watershed is located in Blount County, Tennessee and is a good case study for agriculture and water quality issues in the region. Though the Little River itself is listed by TDEC as one of eight Outstanding Natural Resource Waters (ONRW), after its exit as a pristine mountain stream from the Great Smoky Mountains National Park, it meanders through pastures and later heavy urban development, becoming impaired in many of its tributaries and subwatersheds. The Little River is an area of special concern (Nance, 2002). It supports several state and federally protected species, and is used at some points for recreational purposes. It provides drinking water to thousands of residents in Blount County, and is considered a valuable resource.

Of the 980 km^2 within the Little River drainage basin, 702 km^2 are in Blount County (TVA, 2003). This drainage basin is subdivided into 18 watersheds, many of which are impaired (USGS, 2004). Major sources of pollution vary among pollutants. Residential, commercial, and industrial land, low and medium residue crop land, heavily overgrazed and fair pastures, and livestock with unrestricted stream access contributed significant amounts of at least one pollutant. Pollution loads from feedlots, livestock loafing areas, and other disturbed areas are also very high nonpoint source pollutant contributors (TVA, 2003).

To understand what is contributing to each sample site, landuse maps provide insight to the kinds of activities that go on in the immediate vicinity of that site, which in turn may explain to the water chemistry results. From simply driving the area, it appears to be mainly rural scattered residential and small farming or livestock operations. What is upstream from each site is often not seen or the magnitude of the contributing area not realized. To understand these watersheds and to be better equipped to deal with the problems present in them, it is necessary to have an understanding of the landuse for all supporting areas contributing to each site.

To accomplish this goal, the Little River Watershed IPSI data from July 23, 2002 was obtained from the Tennessee Valley Authority (TVA). All files are in State Plane Projection NAD 83, in units of feet. TVA uses satellite imagery to discern landuse types through infrared images, and follows this with a ground truth for accuracy. Since the data was received directly from the TVA IPSI CD and was not modified by another user, confidence in the accuracy of the data is high. Accuracy is assumed 100%, though it is acknowledged that there is room for human error in the collection and entering of data. Relevant landuse types from TVA classification are summarized as follows: residential, commercial, strip cropped, row cropped, good pasture, fair pasture, heavily overgrazed pasture, feedlot, forest land, and water. Livestock is defined as horses, beef cattle, and dairy cattle, and there can be more than one livestock operation per farm.

A geodatabase and point file, which contained the latitude and longitude coordinates of each of the sample sites, was created in Arc Catalog (ESRI, 1999). The following map layers were imported from the

(Integrated Pollution Source Inventory (IPSI) CD: streams, waterbodies, watershed, and landuse/landclass (lulc). The boundary of HUC12 delineated the watersheds for the Little River. All branches of Nails and Ellejoy Creeks, the stream, livestock site, and landuse layers were selected and clipped from the watershed attribute table (Figures 2-4). All tributaries above the sample points needed to be included in the buffered area. To accomplish this, the watersheds delineated within the watershed file for the clipped area were selected based on their relationship to each point.

Stream portions that were included in the selected area that did not contribute to the sample point were unselected, for a resulting selection of only the contributing area. Lakes and ponds were not included in the supporting areas. These were then buffered with 100 m for greater accuracy (Silva and Williams, 2001), and landuse was clipped based on the sample site. Percentage of landuse was calculated: the sum of the shape area for each row / total sum of the shape area * 100. For each file created with a percentage of landclass for each sample point, the landuse description file was joined to it for a clear picture of what percentage of landclass comprised the greatest portion of contributing area. This process was repeated for each contributing area for each point, until all tributaries within both watersheds had been accounted for (Figure 5).

Summary tables were then created from the data taken from the summed landuse tables for a clearer picture of what landuse types were between each sample site, in the immediate vicinity upstream from each sample site. Final summary tables were created for both livestock and landuse types to understand percentages and numbers of livestock upstream of each sample site. Percentages for landuse for the contributing areas for each sample site were found by summing the three top landuse total percentages for each buffered area contributing to each site and dividing by the total number of buffers included. For Nails, it was straightforward, starting at the first site and including all buffers as all water flows through that site, and subtracting the buffer of each sample site as it was passed. For Ellejoy, some sites only flow though one other site; for example, site 8 does not flow through site 7 and site 6, which are tributaries, but goes straight to site 5. Therefore, the sequence for site 8 is all stream water above site 8, and site 8 to site 5. Site 1 on Ellejoy includes all of the buffers for Ellejoy Creek. Site 2, is all except site 2 to 1, and it continues until all of the tributaries have been accounted for.

Site 1 of Ellejoy Creek is located at the mouth, just before reaching the Little River. It has a canopy of tree cover, is roughly 12 m wide, has a bedrock bottom, and is usually only a little over 0.25 m deep, under normal flow conditions. It is bordered by fields and forested areas, with a thick riparian zone. For the buffer of site 1 to site 2, the greatest percentages of landuse are in forestland and fair pasture. There are also significant amounts of residential area (Table 1). Under normal flow conditions, site 2 of Ellejoy Creek was usually over 0.3 m deep in places, roughly 14 m wide, with a bedrock bottom and no canopy. Active cow pastures, with some riparian zone, border it. For the buffer of Ellejoy site 2 to Ellejoy site 3, the greatest percentage of landuse is fair pastureland, followed by forest and residential (Table 2).

Site 3 on Ellejoy is actually a tributary called Little Ellejoy, and it is bordered on one side by riprap, or rocks that support the steam bank while the other side is a steep bank. Under normal flow conditions, it is about 1 m deep, and 3 m wide. The bottom is bedrock and there is a partial canopy; it is bordered by active pasture and has some riparian zone. Table 3 shows the highest landuse percentage between site two and four to be in forestland, followed by fair pasture and residential. Site 4 on Ellejoy is cut deeply into both banks, with no riparian zone and frequent livestock traffic, especially in the summer. The streambed at this site is thick silt and gravel, and under normal flow conditions the depth is around 0.25 m, and the width is around 8 m. Between site 4 and 5, there is an abundance of fair pasture followed by forestland, as seen in Table 4. Table 5 shows that between site four and six, there is mostly forestland, followed by fair pasture.

Site 5 on Ellejoy Creek is roughly 4 m wide and 1 m deep under normal flow conditions, has no direct overhead canopy, and a thin riparian border on each side. The bed is scoured to create greater depths on the left bank (looking downstream), and is comprised of silt and gravel. Table 6 shows site seven connecting to site five. Once again, the major landuses between these sites are fair pasture and forest. Site 6 is a tributary that connects just above site four, called Millstone, and is a series of shallow riffles which flow into a 2 to 3 m deep pool, widening from about 4 m to 20 m, under normal flow conditions. The bed consists of medium sized stones and gravel, and there is a sparse riparian zone. Table 7 shows that site 8 is connected to site 6. The major landuses are forest and fair pasture. Like site 6, site 7 is a tributary, called Pitner, which meets the main stream just above site five. Site 7 is about 2 m deep and 8 m wide under normal flow conditions, with a silt and sandy bed and heavy canopy cover. The riparian zone is thin but present. Site 8 is a shallow location with a thick sand and silt bed, which measures roughly 5 m across and is about 0.5 m deep. It has a sufficient riparian zone and canopy cover. Table 8 sums the beginning of Ellejoy Creek, all contributing water above the site. It is heavily forested as it begins at the foothills of the Smoky Mountains.

Nails Creek is much smaller and has no tributaries that were sampled. The first site is a beef livestock operation, and the livestock have full access to the stream. There is little riparian zone and no canopy cover. The base flow is about 0.25 m deep and is about 10 m wide. Table 9 shows the buffer between the first and second site on Nails and reveals that there are three major landuses: Fair Pasture, Overgrazed Pasture, and Forest. Site 2 on Nails Creek is located in a residential area and is bordered by a small riparian zone. It has a stone, sand, and gravel bottom and some canopy cover. Average depths are around 1 m, and it is usually about 7 m wide. Table 10 shows Nails site 2 to Nails site 3. Once again, major landuses are forest and fair pasture. Site 3 on Nails Creek has a thick riparian zone and is bordered by trees and pasture. It is usually about 0.75 m deep and 6 m wide, and has a silt, sand, and small gravel bed. Table 11 shows that between Nails site three and all contributing waters of Nails site 4, fair pasture, forestland, and residences are the major landuses. Site four on Nails Creek runs beneath the road through a culvert, has average depths of 0.05 m, and an average width of 4 m. It is cut deeply into both banks, and has a thin riparian zone. The bed is made up of medium sized rocks and gravel, and an auto body shop and residences border it. Table 12 shows the major landuses contributing to this site as being almost equal between fair pasture, forest, and residences.

Several tables were made in summary. Table 13 shows the major contributing landuses for all sites. The highest landuse percentage for each site consistently is forested areas, followed by fair pasture, and residential areas. Table 14 shows the number of livestock operations in contributing areas for each sample site. The highest concentration of cow operations between sites was found between Ellejoy site two and site three, which had 35, followed by 31 operations between Ellejoy site five and site seven, 21 operations between Nails site one and site two, 23 between Nails site two and site three, and 14 between site three and site four. Table 15 sums the livestock operations found in contributing areas to each sample site, and at the mouth of Ellejoy, there are 161 cow operations and 32 horse operations, and at the mouth of Nails, there are 62 cow operations and 8 horse operations, all within the 100 m buffer.

Ecoregion Reference Stream

Ecoregion reference streams were developed under the concept that to truly understand what can be considered impaired and what can be considered acceptable within any given region, there must be a representative standard body of water. Though there were state requirements for steams that were 303(d) listed, there was no way of understanding how they were expected to improve over time, or even why they were considered impaired in the first place. Furthermore, there were indications within these state requirements that biological communities were to be measured with the use of metrics, but it was not specified which metrics were to be used (TDEC, 2002d). With the development of ecoregions, much of the confusion was alleviated.

Ecoregions are delineated by distinctly differing macroinvertebrate communities, and defined by what life diversity is found in reference stream waters. Water quality parameters were not used due to the ease indicator species provide in determining if the water body is impaired. Tennessee is divided into 5 ecoregions shown in Figure 6 (TDEC, 2002a) and within those regions, reference streams were chosen as the best, or most biologically diverse, representative sample of that population of water bodies. Twenty-five subecoregion streams within ecoregions were added to account for as many geological differences as possible within each individual ecoregion. Other state environmental departments and the U.S. EPA evaluated the development of Tennessee's reference stream criteria.

Ecoregion stream reference biological data for Tennessee consists of single habitat semi-qualitative samples of the benthic macroinvertebrate community (Arwine, 2001). This method was chosen because it was easily standardized and yielded consistent results. Multiple metrics were chosen for analysis of samples, and seasonal variability was taken into account. Metrics were equalized across regions by calculating expected ranges, which was done by creating quadrants among the data at either the 10th or 90th percentile, based on if the metric was expected to increase or decrease with disturbance. Once equalized, the regions were combined into a single multi-metric index. Each bioregion had the biocriteria set at 75%

of its maximum possible index score. Testing of these methods was performed in three stages: 60 sites in ten bioregions were sampled, biological criteria were compared to impaired and unimpaired test sites in 6 regions, and probabilistic monitoring data at fifty randomly selected streams in the Inner Nashville Basin were compared to the biological criteria proposed. Other proposed methods were tested as well, but provided less consistent results. Some of the regions were adjusted for large seasonality differences, so an appropriate index based on months is required. Reference sites are monitored on a five-year rotation basis.

Nails and Ellejoy Creeks occur in ecoregion 67, subregions f, g, h, and I, which is one the most impaired regions within the state and therefore does not have a high standard of criterion (Burr, 2004). Water quality data for the reference streams does exist in small, scattered amounts, and is available for download at the U.S. EPA's STORET (STOrage and RETrieval) website (http://www.epa.gov/STORET) or on the U.S. Geological Survey's website (http://www.usgs.gov/). Criteria for benthic metric listings of fully supporting, partially supporting, and non-supporting streams for each ecoregion and sub-region can be found in the Division of Water Pollution Control QS-SOP (Quality System Standard Operating Procedure) for Macroinvertebrate Surveys (TDEC, 2002a)

Water Sampling

While there are different specified containers, preservatives, and cleaning procedures used for various water quality tests, the protocol for surface water sampling for wadeable rivers and streams remains relatively constant. Water is collected facing upstream about a foot under the surface, if possible, to avoid trapping excess nutrients that may be floating on the surface. Bottles are rinsed out with the sample water before the final sample is filled and capped underwater to avoid trapping air bubbles and influencing dissolved oxygen levels. Once the sample has been collected, the samples should be in or transferred into a clean, marked bottle. The sample should be preserved if a significant amount of time will be allowed to elapse before laboratory testing. All sampling notes and site descriptions should be recorded, and bottles should be transported at 4 degrees Celsius. All sampling equipment must be decontaminated before sampling again.

Water sampling at each site on both creeks began in June of 2003 and continued through February 2004. All sites were monitored at three-week intervals, for a total of twelve sets of data. All samples were analyzed in the University of Tennessee Biosystems Engineering and Environmental Science (BEES) water quality lab under the supervision Galina Melnichenko, with the exception of the pathogen tests. These samples were collected from each sample site in state bottles, tagged with state labels, and tested by the Tennessee State Laboratory located behind the University of Tennessee Medical Center, which is contracted by the Knoxville division of TDEC for water quality analysis. For each sampling event, one nutrient sample was collected in a state bottle, which contained preservatives, and dropped off at the state lab with the pathogen bottles. This was done to insure accuracy in nutrient data results from both labs.

Prior to collecting water samples at each site, a YSI 600XL Multiparameter probe from YSI Incorporated in Yellow Springs, Ohio, was connected to the Sonde, or data logger, and placed in the stream. This instrument measured temperature, pH, conductivity, and dissolved oxygen data at each sample site. Before beginning the sample run, the YSI was calibrated for dissolved oxygen according to the barometric pressure. To insure accurate dissolved oxygen data, each month the dissolved oxygen membrane was replaced with new drops of dissolved oxygen calibration fluid under it, and the tip of the probe kept in 3 mm of water during storage times to insure that the membrane did not dry out.

Once the YSI probe was situated and collecting data, the Swoffer Portable flow meter (Swoffer instruments, Incorporated) was connected to its data logger and flow measurements were taken at each site. These were made perpendicular to the stream channel, following a metric tape stretched across the width of the stream. From the left-hand bank, the tape was secured using a stake or branch, and flow was taken from zero depth in one-meter intervals. At each interval, the stream depth and velocity was called out to a person recording the numbers on a data sheet, who repeated it back for clarity. The stream width times the average depth multiplied by the average velocity gave the flow measurement for each sample site. Due to operational failures during several sample runs, the flow meter was unavailable for data collection. In these cases, flow was estimated by timing a rubber duck for one meter with a stopwatch, repeating three times, and averaging the times together multiplied by width and average depth of the stream.

Before collecting water samples, the direction of the flow was determined. A data sheet was completed for each site, which included the date and time of sampling, site number, weather conditions, stream width and depth, velocity data, air temperature, water temperature, relative humidity, pH, conductivity, and dissolved oxygen. These observations were recorded and stored for reference. Photographs were taken once during August at each site, documenting them for visual reference as well.

Water samples were collected in clear polyethylene bottles, which had been rinsed prior to each sampling event with hydrochloric acid and deionized water, and labeled with site numbers. In accordance to TDEC procedures, one grab sample and one duplicate were collected at each site, from the center of the stream. The bottles were held in front of the sampler with the mouth facing upstream, rinsed three times to insure a true sample, filled at approximately a foot below the surface, and capped underwater to eliminate air bubbles. They were then placed in coolers on ice, with the exception of the bottles reserved for BOD-5 day testing, for transport back to the lab. At no time were samples older than six hours before they were placed in refrigeration, due to the time frame designated for the pathogen samples, which were dropped off for analysis at the state lab at the close of each sample event. They were approximately three degrees Celsius when placed in refrigeration.

Chemical Analysis

Laboratory analysis for this study was completed in the University of Tennessee Biosystems Engineering and Environmental Science water quality lab. *Standard Methods for the Examination of Water and Wastewater* (Greenburg et al., 1992) were used for most of the following tests, and methods for each test are individually described in the following section. Parameters tested included Total Kjedahl Nitrogen (TKN), total phosphorous (TP), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), soluble reactive phosphorous), total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), turbidity, biochemical oxygen demand (BOD-5 day), total organic content (TOC), and ammonium (NH3-N). COD was deemed an unnecessary expenditure and not analyzed because test results so closely mirrored the BOD-5 day test results in prior laboratory studies. Analyses of these samples were completed as quickly as possible in the days immediately following the sampling events, to avoid the breakdown of sensitive compounds like ammonia, nitrates, and sulfate, and to insure the best possible data results.

One of the first tests performed upon reaching the lab was the test for biochemical oxygen demand. Developed in England, BOD-5 day can span 5 days, 7 days, or 20 days, depending on the country the test is performed in. The five-day test is popular because it is the minimum time required for a plateau in the microbial population. The concept behind the BOD test is simple, based on the fact that microbial populations require oxygen to consume organic matter and reproduce. A water sample begins with microbials, organic matter and oxygen, and yields microbials, carbon dioxide, and residual organic matter, so the more microbials present, the lower the oxygen levels will be. Introduction of a microbial seed solution increases the amount of microbials present in the solution and lowers the time required to wait for the drop in oxygen levels. In BOD results, around 1-2 ppm is considered very good water quality, 3-5 ppm is considered water of moderate quality, and 9-10 ppm is considered water of poor quality.

For this study, BOD-5 day tests were performed on bottles that had not been chilled prior to testing, in order to have them as close to the accepted 20°C as possible. According to the *Standard Methods for the Examination of Water and Wastewater* (Greenburg et al., 1992) procedures, a microbial seed standard was prepared and mixed for one hour before performing the test. Two ml of seed was added to 200 ml of sample water, mixed, measured, and stored at 20°C for 5 days, whereupon they were again mixed and measured for final results. To obtain the final oxygen concentration, the final reading was subtracted from the initial reading, the f constant of 0.2 was subtracted from that sum, and the final answer was divided by 1.

Like oxygen content, organic matter is significant in the interactions of aquatic systems. It affects nutrient cycling, biological availability, chemical transport, and interactions. There are two ways to measure organic carbon: in its total form or as dissolved. Both are essential portions of the carbon cycle (Hem, 1985). For this study, only the total organic carbon was measured. The concept behind the measurement of Total Organic Carbon is simple, using hydrochloric acid to remove inorganic carbon from the sample in order to measure the organic carbon content. The acid evaporates the inorganic carbon compounds, and once the inorganic carbon is gone, the organic carbon is turned to carbon dioxide by the addition of oxygen and ultra-violet light. A beam of infrared light through the sample then detects the CO2 content.

Ammonia is present naturally in surface and wastewaters, and in lower concentrations in groundwater due to its firm attachment to soils and clays. It is produced mainly through the decomposition of organic nitrogen containing compounds, and by urea hydrolysis (Greenburg et al., 1992). In this study, ammonia was tested by method 8038, or the Nessler method. According to the HACH manual (HACH, 1995), measurements from the spectrophotometer are obtained by using 425 nanometer wavelengths, with an estimated detection limit of 0.06 mg/L of ammonia. A standard, reagent mixed with deionized water, is measured to obtain a zero value, when a beam of light penetrates the sample. This sets the baseline for the samples, and calibrates the spectrometer. Zinc sulfate, serving as a stabilizer, reacts with calcium to prevent production of more calcium ions. It is added to 25 ml of deionized water. After mixing, the sample is then transferred to a proper bottle to fit the HACH 2500 spectrophotometer, and placed in the meter. Color occurs due to the presence of the polyvinyl alcohol-dispersing agent, which shows the reaction between the Nessler reagent and the ammonium ions. Darker color signifies a higher concentration of the ammonia.

Organic nitrogen is defined as organically bound nitrogen in an oxidation state, and does not include all organic nitrogen compounds. It includes proteins, peptides, nucleic acid, urea, and various synthetic organic compounds. Total organic nitrogen, excepting nitrate, and ammonia content in a sample are reported in the Total Kjedahl nitrogen test results. According to the QuikChem Method 10-107-06-2-E (Diamond, 1992), samples are digested with sulfuric acid in 75 ml tubes in a block digester. The samples of Kjeldahl nitrogen are converted to the ammonium cation, and potassium sulfate is added to raise the boiling temperature of the digestion and aid in the conversion to ammonium. After boiling to digest for three hours and resting for one hour, 20 mL of water are added to dilute the digest. Upon transfer of the digested samples to the proper tubes, the LACHAT (Loveland, CO) sampler takes roughly 0.2 ml of each sample, injecting it into the pH-buffer controlled environment within the manifold. Neutralizing the solution converts the ammonium cation to ammonia, and keeps the sulfuric acid from influencing the pH sensitive color reaction. The ammonia is then heated with salicylate and hypochlorite to produce a blue color proportional to the ammonia concentration. Color is magnified by the addition of sodium nitroprusside, and EDTA in the buffer solution prevents precipitation of calcium magnesium. A standard absorbance curve is used to compare the absorbance of each sample, and is obtained from the calibration of standards 5, 2, 1, 0.5, 0.25, 0.1, and 0 mg/L of nitrogen. This process produces a TKN concentration for each sample.

The block digester method is used to measure total phosphorous as well. Between the ranges of .01 and 5 mg/L of phosphorus, this method can be utilized, and will detect as low as 0.005 mg/L of phosphate. The use of a mercuric oxide catalyst converts the samples' phosphorous into the orthophosphate anion. Potassium sulfate is also added to raise the boiling temperature and to speed the conversion to orthophosphate. The digest is diluted with 20 ml of water, as in the TKN procedure. When in place in the LACHAT sampler, the orthophosphate ion reacts with ammonium molybdate and antimony potassium tartrate to form a complex, which is reduced with ascorbic acid to form a blue light-absorbing complex. The amount of light absorbed is proportional to the orthophosphate concentration of the sample (Liao, 1993).

Orthophosphate, or inorganic phosphorous, in a sample is also measured by the LACHAT direct colorimetric procedure, but does not require digestion (U.S. EPA, 1983). An unaltered sample is injected into the Lachat sampler after calibration with the proper reagents. In this particular study, Chloride, nitrite, nitrate, and sulfate were measured using DIONEX (Sunnyvale, CA), an ion chromatography sampler that allows measurements of more than one ion at the same time. Water samples were passed though a 0.45μm glass filter to remove suspended solids, put in labeled plastic tubes, and capped. According to Greenburg et al., (1992) the ion chromatography sampler injects the samples' into fluid bicarbonate, which then passes through ion exchangers. Separation of anions occurs within the exchanger, and they become very reactive within a fiber suppressor column. The bicarbonate fluid is changed into a sluggish and less reactive carbonic acid. In that state, anions are measured at their peak states. As no ions stay within the column for the same amount of time, determining peaks is possible by noting the time each ion stays within the column. A measurement of the area beneath the peak of each anion measures individual concentrations.

Measurements of solids involve total solids (TS), suspended solids (TSS), and total dissolved solids (TDS). For total suspended solids, the weight of individual 2.0μm paper filters are measured, and 100 mL of water is passed through a vacuum glass filter. The wet filters are then placed in a shallow marked tin drying cup, and put into an oven heated to 180 degrees C. After a 24-hour period, they are removed, placed in a desiccator, and weighed again. A subtraction of the first weight (filter) from the second weight (filter + residue) produces the amount of total suspended solids found within that sample in mg/L. Finding concentrations of total solids is similar, without filtering. An open tin cup is labeled with a site number and weighed, and 25 ml of sample water is poured into it. It is also placed in the 180-degree oven and left for a 24-hour period. Upon removal from the oven, each cup is placed in a desiccator and weighed again, and the initial weight (tin) is taken from the final weight (tin + residue) to produce a concentration of total solids for each sample. For this study, the data was adjusted from 25 ml to 1000 ml by multiplying by 40. Total dissolved solids are a subtraction of total suspended solids from total solids.

For measures of turbidity, the meter is calibrated using the four standard bottles provided with the kit, turning each standard in the meter until the lowest reading is found, and then waiting until the meter display stabilizes and prompts for the next standard. When calibrated, the sample bottle is shaken, and a sub-sample extracted. This is done three times for each sample from each bottle, re-capping and shaking it before extracting each of the three sub-samples. All three sub-samples are put together into the standard test bottle for the turbidity meter after extracting them, until the standard bottle is full. The bottle is then capped and dried off, using Kim-Wipes to insure that as few particles as possible are left on the outside of the glass. After placing the standard bottle into the center of the turbidity meter, it is turned slowly, with the arrow button held down until the smallest reading is found. The arrow button is then released and several seconds are allowed for the meter to stabilize. The final figure is recorded. Three readings are taken from each sub-sample from each sample bottle (Harden, 2002).

In order to better understand what each stream is contributing to the Little River by way of sediments and nutrients, metric tons per year were calculated as a contributing load. This was done by finding a constant value for metric tons per year with the following equation, where X=concentration, and Q=flow:

$$\frac{1\ L}{0.001\ m^3} * \frac{X\ mg/L}{1\ L} * \frac{1\ kg}{1{,}000{,}000\ mg} * \frac{1\ \text{Metric Ton}}{1{,}000\ kg} * \frac{Q\ m^3}{1\ sec} * \frac{3.1536 * 10^7\ sec}{1\ yr} = \frac{\text{Tonnes}}{\text{Year}}$$

The constant, when solved for, was 31.53, and this number was multiplied by the individual flow measurements (m^3/sec) for each of the following mg/L measurements: Total Kjedahl Nitrogen, ammonia, nitrates, total phosphorus, orthophosphate, total suspended solids, total dissolved solids, and total solids. It should be noted that flow measurements were not taken during high flow events, which is consistent with the grab sample method. Therefore, these loading values are based on measured flow for each sampling event.

Benthic Sampling & Analysis

Benthic Macroinvertebrate collection for Nails and Ellejoy Creeks occurred in August of 2003, and was conducted according to EPA standards as interpreted by TDEC. Sample sites for this collection were chosen at the mouth of each stream and at each major confluence. There were four sites on Ellejoy: Tuckaleegee Pike, Little Ellejoy, Millstone Branch, and Pitner Branch, and three sites on Nails Creek: Andy Harris, Conley Farm Ford, and Baker Road. TDEC staff and myself sampled using a one-meter by one-meter fine mesh kick net fastened between two wooden dowel handles for the collection of specimen.

The two largest riffles, or stretches in the stream where flow is broken and fast, at each site were selected for downstream sampling. One person spread the net below the riffle and held it as low as possible without loosing any debris, while another secured the net along the bottom of the stream with rocks and kicked up a one-meter by one-meter section in front of the net for one minute. Rocks were wiped with a hand and removed from the bottom of the net, which was then carefully lifted out of the water so as to contain the entire sample. The net was then placed upright in a bucket with a fine wire mesh bottom, and rinsed off by one person with water from the stream collected in another bucket while the other person held the net taut in the center to allow for thorough rinsing. When as little as possible debris remained on the net, it was removed and placed on the side of the stream, and one person examined it for any creatures that continued to cling to the mesh, which when found were removed with forceps and placed in a plastic container. The other person repeatedly rinsed the sample in the mesh bottom bucket to remove as much sediment as possible and picked out the larger pieces of debris.

When the sample was rinsed clear, it was added to the plastic container containing the creatures remaining on the net. The samples from both riffles at each site were placed together in the same plastic jar, and a solution of 98% ethanol was added from a gallon jug to the jar until the entire sample was immersed. A penciled site label was added to the jar before it was capped, and the cap was labeled in permanent marker with the same information. This process was repeated twice at each site on both creeks for a total of seven benthic samples. The samples were then shipped to a state lab for identification down to the species level. Results were returned to TDEC in March of 2004. Old benthic data, starting in 1981 and continuing sporadically through 2000, for both the Nails and Ellejoy Creeks were obtained from TDEC records and included in the benthic analysis of both streams.

Benthic analyses were performed at state labs in Nashville, TN, and were conducted in accordance with the TDEC state procedures. Protocol for these procedures is found in the Division of Water Quality System Standard Operating Procedures for Macroinvertebrate Stream Surveys (TDEC 2002a). A numeric value was calculated for the raw benthic data for each of the seven biometrics specified by state requirements. Organisms were identified to the genus level except for those too young or damaged to identify.

The first two biometrics are qualitative. The first of the seven is Ephemeroptera, Plecoptera, Trichoptera Richness (EPT), which is the total number of genera within these orders. Taxa that are only identified to family were included only if they were the only taxon found in that family, or were distinct from other taxa identified to genus within the family. The second biometric is Taxa Richness (TR), which is the total number of genera found within the subsample. Once again, taxa that can only be identified to family are included if it is probable that they are distinct from other taxa identified to genus within family.

The remainder of the biometrics are quantitative. The third biometric is the percent of oligochaetes and chronomids (% OC). It is calculated by dividing the total number of Oligochaeta + Chironomidae by the total number of individuals in the subsample, times 100. The fourth biometric is the Percent EPT Abundance (% EPT), and is calculated by dividing the number of Ephemeroptera + Plecoptera

+ Trichoptera) by the (total number of individuals in the subsamples, times 100. The fifth metric used is the North Carolina Biotic Index (NCBI) and is calculated by summing the number of individuals within a taxon multiplied by the constant tolerance value of a taxon, and dividing that number by the total number of individuals in the subsample. The sixth biometric is the percent contribution of the single most dominant taxon (% Dominant), and is calculated by dividing the total individuals in the single most dominant taxon by the total individuals in the sample, times 100. The seventh and final biometric is the percent contribution of organisms that build fixed retreats or have adaptations to attach to surfaces in flowing water (% Clingers), and is calculated by dividing the number of clinger individuals by the total individuals in the sample, times 100.

After calculating values for each of the seven biometrics, the data is equalized by assigning a number score of 0, 2, 4, or 6, based on comparison to Ecoregion reference data according to bioregion. The seven scores are totaled, and the biological condition of the stream is determined by using a predefined score table. This total results in the SQ Index score, which is used to rate the stream as fully, partially, or nonsupporting. The non-impaired category is equal to or greater than the proposed biocriteria. Details of this metric summary can be found in QSSOP manual for benthic macroinvertebrates (TDEC, 2002a).

Statistical Analysis for Water Quality and Benthic Macroinvertebrates

Statistical analysis for the water quality analysis was performed in SAS, version 9 (Cary, NC). Due to the fact that the water that flows though the most upstream site in most cases will flow though the other sites until it reaches the mouth, the data from each site is not a specific, independent entity. Because of this, experimental units would have to be streams, making a sample size of two, and therefore too small to determine any statistical differences among experimental units at an acceptable confidence level. While there may be some differences in reality, the null hypothesis of no significant differences would have to be accepted. To still have statistics that are acceptable, and to be able to understand what is happening in the aquatic system in both streams, the statistics that were used are more qualitative in nature, showing linear relationships for comparison of water quality parameters. Correlations were used for more quantitative data between sediments and nutrients.

The general linear mean (GLM) procedure was used to compare water quality variables by site, with reference stream data, and to compare metric tons/yr of each sediment and nutrient constituent. Tables of variables and values, and box and whisker plot graphs were produced for each variable measured that was of interest in this study: Total Kjedahl Nitrogen, nitrate, ammonia, total phosphorous, orthophosphate, total dissolved solids, total suspended solids, total solids, BOD-5 day, dissolved oxygen, and pH.

The Pearson Correlation was performed at a 0.05 level of significance for TKN, nitrate, total phosphorous, orthophosphate, total suspended solids, total dissolved solids, and total solids, and on thetonnes per year values for these parameters. Charts that were produced show levels of significance of comparisons between parameters. Multiple Comparisons, or mean separations, were performed to determine if there were differences among variables at individual sites. The ANOVA F-test tells whether means are significantly different for each other, but does not tell which means differ. For any variables that showed differing means at a statistically significant level, a Tukey's honest mean test was performed to tell which of the sites specifically accounted for the significant relationship.

Statistics for benthic analysis were performed in EcoSim (Gotelli and Entsminger, 2003), an ecosystem simulation program that runs the following null models: Co-Occurrence, Macroecology, Niche Overlap, Size Overlap, Species Diversity, Standard Tests, and Guild Structure. The model allows for testing of community patterns with raw, non-experimental patterns. A matrix was generated from benthic data including the year of 1998, 1999, 2000, and 2003, using 1's and 0's for indication of presence or absence. EcoSim runs the data with 5,000 randomizations and compares patterns of the original data matrix to the randomized patterns, for a measure of co-occurrence. This model is good when desiring to know if species richness varies from ecosystem to ecosystem depending on water quality, which is why it was chosen for this particular study. The test utilized from this model for Nails and Ellejoy Creeks benthic macroinvertebrates was the Principle Component Analysis.

AQUATOX Computer Model

Use of the AQUATOX, release 2 (Park et al., 2004) computer model was incorporated to simulate the passage of time to predict the fate of the aquatic system in the Nails and Ellejoy Creeks if the stream continues at the same rate, with the same levels of input of sediments and nutrients. Model parameters included sediment and nutrient data, benthic, fish, and aquatic plant life data, chemical data, and physical parameters, such as temperature, pH, light exposure, flow, wind velocity, bank slope, geographic location, and stream geomorphology. Parameters added to the model from this study included benthic data, sediment and nutrient data, temperature, pH, flow, stream geomorphology, and geographic location. Default values from a rural agricultural stream in the southeast region of the United States were used for parameters that were not measured within this study. Due to the lack of much actual data for the Nails and Ellejoy Creeks, the model was only used as an aid to approximate stream stability now and over the course of ten years, and was not made a larger part of this study.

One mean value was entered for each sediment and nutrient, and all flow, temperature, and pH data were imported from Excel spreadsheets. Benthic and plant selections were available so as to have a possibility of two species from each class of feeders or algal growth. Chemical variables could be added at random as influencers, and after the simulation had run, the results were tabulated and graphed according to which variables were selected for viewing. Time was always plotted on the X-axis, and the desired variables that contained the same units were always graphed on the Y-axis. Additional variables with other units could be viewed on the same graph by adding an additional X-axis. Simulations of intervals from 2003 to 2013 were run for both streams; the assumption that landuse does not change drastically being a drawback.

Chapter 3

Results and Discussion

Nails and Ellejoy Creek Mean Water Quality Parameters

Comparisons of water quality using the general linear mean procedure at both the Nails and Ellejoy Creeks showed no difference among sites. Tables of each GLM procedure for each variable are provided in Appendix A, and graphs of the tabulated data are provided in Appendix B for visual comparison. The graphs bar, or box, goes from the 25th to the 75th percentile between the high and low points of measurement. The whiskers go from the 10th to the 90th percentile from the top of the box. These values were chosen because of the 12 observations for each site; 1outlier is needed above and below the points. Though a trend may appear to increase or decrease, over time the variability is so large that it may not be an actual trend.

Levels of nutrients on both creeks were larger than the reference stream value, as expected due to the poor riparian zones, the unrestricted livestock access, and the agricultural nature of the landuse. Orthophosphate was generally low (0.07-0.08 mg/L), reflecting the low levels that were detected in the lab. The average mean across all sites and all samples tested for TKN was 0.35 mg/L. Nails Creek sites averaged 0.26 mg/L. Both streams were higher than the reference stream value of 0.09 mg/L (Table 16, Figure 7). Ammonia-N had a mean average of 0.16 mg/L for all sites on Ellejoy. Nails Creek had a mean of 0.14 mg/L for all sites. Both were higher than the reference stream value of 0.01 mg/L (Table 17, Figure 8). Total Nitrate-N for Ellejoy Creek had a mean value of 2.59 mg/L, and Nails had a mean Nitrate-N value of 3.30 mg/L, which was much higher than the 0.90 mg/L level listed by the reference stream (Table 18, Figure 9). Total Phosphorus at Ellejoy was a mean value of 0.08 mg/L across all sites, and Nails Creek mean was 0.07 mg/L across all sites. Both of these values were slightly higher than the reference stream value (Table 19, Figure 10). The orthophosphate mean value for Ellejoy was 0.02 mg/L, and for Nails it was 0.02 mg/L. No reference data was available for orthophosphate (Table 20, Figure 11).

Sediments for both streams showed interesting data. Mean Total Suspended Solids for both Ellejoy and Nails were well below the reference stream acceptable value of 5 mg/L, at 0.36 mg/L and 0.47

mg/L, respectively (Table 21, Figure 12). This is because no sampling took place during high flow events, and the water that was filtered was almost always clear. Total Dissolved Solids were above the reference stream value of 170 mg/L, Ellejoy having 229.12 mg/L, and Nails having 240.41 mg/L (Table 22, Figure 13). There was no available data for Total Solids. Ellejoy Creek had a mean value of 229.13 mg/L across sites, and Nails Creek had a mean value of 240.42 mg/L across sites (Table 23, Figure 14).

No reference stream data was available for biological criteria. Biochemical Oxygen Demand values were 2.20 mg/L in Ellejoy Creek, and 2.22 mg/L in Nails Creek (Table 24, Figure15). Dissolved Oxygen at Ellejoy was 9.60 mg/L, and for Nails, 10.22 mg/L (Table 25, Figure 16). For the pH values on both streams, Ellejoy had a mean across all sites and all samples of 8.05, and Nails had a mean across all sites and all samples of 8.09 (Table 26, Figure 17).

The amount of metric tons per year contributed into the Little River from these streams were also interesting to see, as sometimes the holistic picture of what is actually going on within a watershed can be lost in the observing of individual values. Total contributions of sediment and nutrients into the Little River from Ellejoy and Nails Creeks per year are of interest because knowing where problem areas are located within a watershed will aid in planning for the reduction of these pollutants. For nutrients, TKN contributions from Ellejoy Creek are 3.926 tonnes/yr, and contributions from Nails Creek are 2.85 tonnes/yr (Table 27, Figure 18). For Ammonia-N, Nails contributes 2.36 tonnes/year into the Little River, and Ellejoy, 1.92 tonnes/yr (Table 28, Figure 19). Nitrate-N from Ellejoy consists of 21.94 tonnes/yr, and 30.04 tonnes/yr from Nails Creek (Table 29, Figure 20). This value is surprising, as Nails is a much smaller stream than Ellejoy Creek. Total Phosphorus from Ellejoy Creek into the Little River is 0.76 tonnes/yr, and 0.64 tonnes/yr comes from Nails Creek (Table 30, Figure 21). Orthophosphate from Ellejoy Creek contributes 0.25 tonnes/yr, and Nails contributes 0.24 tonnes/yr (Table 31, Figure 22).

For sediments, Nails Creek contributes 4.95 tonnes/yr of total suspended sediments, and Ellejoy contributes 3.42 tonnes/yr (Table 32, Figure 23). Total dissolved solids are contributed to the Little River from Nails Creek at a rate of 2120 tonnes/yr, and from Ellejoy at a rate of 2008 tonnes/yr (Table 33, Figure 24). Total solids come from both these stream respectively at rates of 2120 and 2009 tonnes/yr (Table 34, Figure 25). Nails Creek shows evidence of much more erosion and sediment input than is acceptable for a stream of its size. Figures 26-29 and tables 58-59 provide summary information. Once again, these figures are related to flow measurements for each sampling event, and concentrations are adjusted for flow.

Ellejoy Creek Water Quality

To give an overview of what is going on in the Ellejoy area, an evaluation of the Ellejoy Creek watershed by TVA in 2003, when sampling of this watershed began, is provided to produce the following summary information. Ellejoy Creek Watershed has 286.5 km of total stream, 10% of which have eroding banks. It receives roughly 1.2 m of rain annually. Within Ellejoy Creek, there are 29,795 m of eroding streambank, 22,897 m of eroding road bank, and 0.46 km of unpaved roads, eroding at a rate of 0.01, 0.08, and 22 metric tons per hectare per year respectively. A total of 911.7 metric tons is estimated to be lost from stream banks each year. There are 36.8 km^2 of total pasture: 3.7 km^2 of good pasture, 28.6 km^2 of fair pasture, 4.4 km^2 of heavily over grazed pasture, and 7 feedlot loafing areas. There are 3.3 km^2 of total row cropland: 2 km^2 of high residue row crop, 1 km^2 of medium residue, and 0.16 km^2 of low residue. Livestock operations are classified in this document as large: 100 head, medium: 50 head, and small: 25 head of livestock. A total of 93 beef livestock sites are identified (31 medium, 18 small), 50 of which are adjacent to the stream. A total of three dairy sites are identified, all medium size, and all bordering the stream. Twenty-six horse sites are present within the watershed, 3 of which are adjacent to the stream. There are 39 sites with obvious stream access, 231 with probable access, and 251 with potential access. Over 50% of the creek riparian zone is classified as marginal. Ellejoy creek has 6.6 km^2 of total urban landuse, 5.7 km^2 of which are residential. Only 3% of the watershed is considered impervious. Of the landuse classes, agriculture is shown to produce 82.6% of the total phosphorous, 74.9% of the total nitrogen, and 70.7% of the total suspended solids (TVA, 2003).

With physical characteristics of this watershed in mind, the data was checked for correlations between variables. Correlation tables are helpful to observe which variables, if any, affect other variables at a statistically significant level. Whether or not there is a positive correlation is determined by the P-value; less than 0.05 is considered significant. Sample size restricts the ability to obtain a high level of statistical significance. Once again, tables of the following correlations appear in Appendix A. For sediment correlations, total dissolved solids were perfectly correlated with total solids, due to the fact that total dissolved solids are a subtraction of total solids and total suspended solids (Tables 35-36). Tables 37-38 shows the nutrient correlations, and many show a small positive correlation, as anticipated from an agricultural watershed with animal access to the stream. Correlations of sediments and nutrients are shown in Tables 39-40, and while there are some positive correlations, they are limited by sample size and so are very slight. Tables 41-42 shows correlations for tonnes per year of sediments and nutrients, which are all positively correlated at a 0.05 level of significance.

The Mean Separation test was performed among variables. The only one that was statistically different among sites was nitrate concentrations in Ellejoy Creek ($F = 2.49$, $P = 0.02$) (Table 52). Tukey's Studentized Range test offered a closer look at where the variation among sites occurred, protected from Type One errors at alpha = 0.05. This test revealed that site 3 and site 6 differed from the others (Tables 51-53). Both of these sites are tributaries. Site 3, Little Ellejoy, is classified as partially supporting in the newly acquired benthic and habitat assessment for 2003. This is not surprising, as the major landuse for this tributary are fair pasture and residential, and it has the largest amount of livestock operations of any of the sites along Ellejoy Creek. Site 6, Millstone, is listed as fully supporting and will in all likelihood be removed from future 303(d) listing (Burr, 2004). Its major landuse is forest.

Ellejoy Creek, however, is listed as impaired, and will not be removed from the upcoming 303(d) listing. The TVA study revealed that a large amount of sediments and nutrients are contributed by agriculture, and that many of the livestock operations are adjacent to the stream, having a direct impact on these contributions. Should the landuse change as drastically as expected, there will be a reduction in the number oftonnes per year that are contributed from agricultural sources, but the residential areas moving in may come with their own set of problems, as seen in the Nails Creek data.

Nails Creek Water Quality

From the same TVA study, summary information of Nails Creek was provided. Nails Creek Watershed has 103 km of total stream, 21% of which have eroding banks. It receives roughly 1.2 m of rain annually. Within Nails Creek, there are 20,959 m of eroding streambank, 8,502 m of eroding road bank, and 0.12 km of unpaved roads, eroding at a rate of 0.01, 0.08, and 23 metric tons per hectare per year respectively. A total of 483 metric tons is estimated to be lost from stream banks each year. There are 18.14 km^2 of total pasture: 483.5 km^2 of good pasture, 13.4 km^2 of fair pasture, 3.12 km^2 of heavily over grazed pasture, and 10 feedlot loafing areas. There are 3 km^2 of total row cropland: 1.2 km^2 of high residue row crop, 0.98 km^2 of medium residue, and 0.78 km^2 of low residue. A total of 52 beef livestock sites are identified, 30 (11medium, 19 small) of which are adjacent to the stream. Two livestock sites are dairy, large and medium, and both border the stream. Fifteen horse sites are present within the watershed, 2 of which are adjacent to the stream. There are 26 sites with obvious stream access, 115 with probable access, and 136 with potential access. Over 50% of the creek riparian zone is classified as marginal. Nails Creek has 9.8 km^2 of total urban landuse, 8.2 km^2 of which are residential. Seven percent of the watershed is considered impervious. Of the landuse classes, agriculture is shown to produce 70.8% of the total phosphorous, 70.4% of the total nitrogen, and 77.1% of the total suspended solids (TVA, 2003).

Pearson Correlations for Nails Creek, like Ellejoy Creek, revealed small positive correlations between sediments and nutrients. The total solids and total dissolved solids, as noted in the Ellejoy Creek, remained mathematically correlated (Tables 44-50). The Mean Separation test for each variable in mg/L and tonnes/yr revealed no significant differences among variable concentrations among sites. No Tukey's Studentized Range tests were performed on this data. Mean Separation data for both streams is available in Appendix C.

Overall water quality for Nails Creek is not high, as seen by this and the TVA study, in which many of its variable concentrations were greater than Ellejoy. While this is not a comparison study, it is hard not to notice that Ellejoy Creek has 286.5 km of stream, and Nails Creek only possesses 103 km of stream. For being less than half the size of Ellejoy, Nails Creek is significantly more impaired, contributing almost the same amount of tonnes per year of sediments and nutrients as Ellejoy and doing so with less pasture area and livestock operations. Residential areas in this watershed are more than half of that present within Ellejoy, which is something that should perhaps be the subject of further study.

Nails and Ellejoy Creek Benthic Macroinvertebrate Statistics

Because of high sediment and nutrient loadings from both study creeks, it is interesting to see what kinds of interactions are going on between benthic communities and their physical habitats. Multivariate analyses have long been used productively in ecological research endeavors such as this (Gauch, 1982; McGarigal et al., 2000). Principal Component Analysis (PCA), as well as other factor analytic procedures, has primarily been used to reduce dimensionality, or the number of variables, of common data sets in such as way as to generate hypotheses regarding the underlying mechanisms generating trends. Graphs produced from this analysis show clustering of variables with similar interactions, separating objects that are different and representing their distances more accurately than those among similar objects.

Variability is summarized by finding a set of mutually orthogonal axes that successfully explain the greatest amount of variation remaining in the dataset. These axes are called the principle axes, which are found by estimating a set of principle components, which are regression equations. Two or three principle components usually account for most of the variation within the data, because these components are extracted successfully by using the criterion that the following extracted components are orthogonal to the components extracted previously, and that the next component to be derived is the one that explains the most residual variation in the data. Therefore, the variation is accounted for in the first components, while the lower components have none.

Once the PCA has been run, each variable has made some contribution to the variability, though not necessarily in the same proportion as the other variables, and not correlated with the other variables. The result is that principle components can identify sets of variables with corresponding variability, aiding in the recognition of overall patterns of variability within the layers of influence. There are two modes PCA, R mode, or Q mode. R mode was used in this study because of the need to identify combinations of correlated variables, which can explain patterns of variation. Because parameters were in the same units, a correlation matrix was generated and the eigenvalues, which determine the number of factors to retain, and eigenvectors, which are the weights that relate the scaled original variables to the factors, were extracted from the matrix, so that each of the eigenvalues are maximized. Projecting the original data onto the space defined by the extracted principle components generates a set of principle component scores for the original objects.

In EcoSim, the co-occurrence test for Nails and Ellejoy Creeks showed that there were major patterns within communities, as none of the 5,000 randomizations produced the same community structure. PCA analysis, R mode, in NCSS Statistical Software (Gauch, 1982; McGarigal et al., 2000) was used to generate trends and associations between organisms, sites, and environmental variables for Nails and Ellejoy Creeks combined, for benthic data collected in 1998, 1999, 2000, and 2003. Figures 30-32 are the first three axes representing the environmental and habitat parameters. These graphs show that PCA trends are, not surprisingly, consistent with the degree of landuse modification surrounding the streams. Using environmental variables, the first 3 principle component axes account for 81 of the observed variance in the data set. These figures are summarized in Table 55, which also shows the eigenvectors and eigenvalues for each of the three axes.

These graphs can be interpreted as having channel current axes, and show that Bank Stability, Bank Vegetation, and Riparian Vegetative Zone Width, or stable, strong streambank support, are clustered above Sediment Deposition, Embeddedness, Epifaunal Substrate, and Frequency of Riffles, or parameters that influence benthic habitat. It seems that these two groups of variables are directly influencing each other. This makes physical and biological sense, as with a decrease in riparian presence and a greater percent of stream bank erosion, the more embedded in sediment the substrate becomes, which decreases the riffle dependent benthic habitat. Likewise, the greater riparian presence, the more favorable conditions are for fully supporting habitat.

Figures 33-35 represent the three axes that are present in the species PCA. Table 56 shows that 55% of the variability within species interactions is represented in these three axes. The axis reveal large groupings of nutrient tolerant organisms, with separation of organisms either uninfluenced by the presence or absence of nutrients, like riffle beetles, or unable to cope with it well, like shredders. This indicates the anticipated result of finding that species diversity is extremely limited by high amounts of nutrients. Figure 35 shows a separation of pollution tolerant and intolerant species alike, illustrating that pollution tolerant organisms also exist and thrive in conditions favored by the more sensitive species as well. Table 57 shows the species that separated from the clusters by common name, family, and species. Numbers within this figure represent species, but names were only assigned to species that were obviously separated from the rest. Drawings of species that are pollution intolerant are shown in Figure 36. Drawings of somewhat pollution intolerant species can be seen in Figure 37, and drawings of pollution tolerant species can be seen in Figure 38.

Ellejoy Creek Benthic Macroinvertebrates

Ellejoy Creek benthic macroinvertebrates collected in August of 2003 showed three of the five sites sampled to be fully supporting, according to TDEC metrics. The others were listed as partially supporting. Site 1, sampled at the mouth, was listed as fully supporting. This is not surprising, as site 1 flows intermittently over riffles (small rapids), and runs (long stretches of flat water), which is ideal for good habitat. Also, site 1 has good canopy cover, stays relatively cool during the summer months, and has a thick riparian zone. Sixty-four of the organisms collected were nutrient tolerant, and it received an SQ Index score of 34, which, when compared to the reference stream value in the Macroinvertebrate handbook (TDEC, 2002a), was within the fully supporting range. The SQ Index score is obtained from totaling the metric values of the seven metrics delineated in the state manual. Optimal scores were obtained in habitat assessment categories of velocity/depth regime, channel alteration, frequency of riffles, and bank stability. Suboptimal scores were obtained for the habitat assessment categories of epifaunal substrate, or available underwater cover, embeddedness of the channel, sediment deposition, channel flow status, vegetative protection, and riparian vegetative zone width. Site 1 passed the habitat guidelines for its subregion. Habitat score categories are defined in a sample habitat assessment field data sheet, Table 54.

Site 3 was the second location for the collection of benthic macroinvertebrates from the Little Ellejoy tributary. It initially received a fully supporting SQ Index score of 32, which fell into the category of partially supporting in the state manual. It was noted, however, that it passed by default results, as Cheumatopsyche dominated it, a nutrient tolerant EPT Clinger, which is good to have, though maybe not in such abundance. When recalculated to adjust for the amount of these organisms, it received a partially supporting score of 26. Eighty one percent of the organisms collected were nutrient tolerant. Optimal scores obtained in the habitat assessment categories of channel flow status, bank stability, vegetative protection, and riparian vegetative zone width. Suboptimal scores were received in the categories of embeddedness, velocity/depth regime, channel alteration, and frequency of riffles. Marginal scores were received in the categories of epifaunal substrate, and sediment deposition, and poor scores were received in category of bank stability. Site 3 passed the habitat guidelines for subregion, which indicated the low standards of this area.

Site 5 was the third benthic samples taken, also listed as partially supporting, with a SQ Index score of 28. Of the organisms collected, 54.8% were nutrient tolerant. The habitat guidelines for this site were not met, resulting in a failing habitat score. In the suboptimal category were velocity/depth regime, channel flow status, and vegetative protection. In the marginal categories were epifaunal substrate, sediment deposition, bank stability, and riparian vegetative zone width. Embeddedness was given a poor score. Site 5 is bordered by pasture, and has livestock influences directly on its banks.

Site 6, Millstone Tributary, was the fourth organism sample taken. It was given an SQ Index Score of 135, and was listed as fully supporting. This is not surprising, as it was the most pristine of all the sample sites in this study. Of the organisms collected, 37.9% were nutrient tolerant. Habitat guidelines were met for a passing score. Within the optimal category were embeddedness and velocity/depth regime. Within the suboptimal category were epifaunal substrate, sediment deposition, channel flow status, channel alteration, frequency of riffles, bank stability, vegetative protection, and riparian vegetative zone width.

Site 7, Pitner Branch, was the final collection taken from Ellejoy Creek. It received a SQ Index score of 34, which is fully supporting. Of the organisms collected, 71.3% were nutrient tolerant. However, the habitat guidelines were not met, resulting in a failed score. Epifaunal substrate, embeddedness, velocity/depth regime, sediment deposition, channel flow status, channel alteration, frequency of riffles, bank stability, vegetative protection, and riparian vegetative zone width were listed as suboptimal. These are realistic classifications, as site 7 is influenced by mainly pasture, with many livestock sites.

Nails Creek Benthic Macroinvertebrates

Benthic Macroinvertebrates for Nails Creek were collected at sites 1, 3, and 4. Each, surprisingly enough, were classified as fully supporting. Nails site 1, located at the beef livestock operation, received a SQ Index score of 132, and 72% of the organisms collected were nutrient tolerant. It passed the habitat guidelines for the subregion. Velocity/depth regime was optimal. Epifaunal substrate, embeddedness, sediment deposition, channel flow status, channel alteration, bank stability, and vegetative protection were categorized in the suboptimal category. Riparian vegetative zone width was in the marginal category.

Nails site 3 was the second site sampled in Nails Creek. It received a SQ Index score of 32, which is fully supporting, and 59.8% of the organisms collected were nutrient tolerant. Site 3 failed the habitat guidelines. Velocity/depth regime and channel flow status were optimal. Embeddedness and channel alteration were listed as suboptimal. Epifaunal substrate, sediment deposition, frequency of riffles, bank stability, vegetative protection, and riparian vegetative zone width were marginal. Bank stability was poor.

Nails Creek site 4 was the final site sampled for benthic organisms, receiving a SQ Index score of 36, which classifies it as fully supporting, and 62.1% of the organisms were nutrient tolerant. It did not pass the habitat assessment score. Channel flow status and channel alteration were classified as suboptimal. Epifaunal substrate, embeddedness, sediment deposition, bank stability, vegetative protection, and riparian zone width were classified as marginal. Frequency of riffles was poor.

Overall, benthic results form the 2003 collection were better than expected for both Nails and Ellejoy Creeks, due in part to the cool, wet summer that created much more favorable conditions for aquatic life than have been present in previous years. Many of the sites that obtained a fully supporting classification have not done so for quite some time. This positive improvement in aquatic life may indicate an increase of species diversification that could possibly increase with improvement of riparian zones along the stream bank.

AQUATOX

Use of the AQUATOX model, while interesting, was not very helpful to this particular study for several reasons. The first and foremost being that population pressure is increasing and Blount County is urbanizing (TVA, 2003), and the model does not account for landuse changes over time. According to Jonathon Burr, TDEC biologist for this ecoregion, the landuse change within the next ten years is expected to be drastic, changing from rural residences and farmland to mostly subdivisions. Being based on the assumption that the initial amounts of toxicants and the traditional nonpoint source polluters are continually imputed into the aquatic environment at the same rate over time, the model creates accumulation of polluters and toxins based on how the study stream changed in temperature, pH, and flow for the period of the data collection. In the case of the Nails and Ellejoy Creeks data collection, the data was representative of three seasons, summer, fall, and winter. To input the flow, pH, and temperature data collected during these seasons and to create a ten-year simulation may in fact leave out a good portion of biological and physical variation.

Another problem with using AQUATOX in a study of this nature is that most of the variation within the model is caused by the addition of one or more environmental toxins to the study area's flow, temperature, and pH data. Sediments and nutrients are modeled as constituents of the physical environment, but create relatively little significant variation, as exemplified when running the model with the Nails and Ellejoy data, indicating that the model is better suited to model chemical additions to an aquatic environment. Though there are options to chose from for the kind of aquatic system that is modeled, AQUTOX seems best suited for lake and pond environments, where chemicals accumulate over time in sediment. Modeling a stream or river environment is incredibly challenging, due to the many variables present in natural systems such as these. Scientists are continually trying to better comprehend these variables (Lake, 2000). Much is still not known about the natural interactions within flowing water systems, and the reaches of scientific understanding limit ecological risk models. While this does not discount aquatic modeling, it does suggest that they may be limited to specific natural environments of a single type.

Tables and graphs simulating the next ten years of water quality in the Nails and Ellejoy Creeks were not included in this document due to the issues listed above, and to the fact that many values needed to run the model were default settings due to absence of study data. While the default values came from the same general climate and topography, confidence in the models output was not high. Graph behavior, however, was stable, showing no drastic increases in sediments or nutrients within either the Nails or Ellejoy Creeks over the ten-year period.

Discussion

The overall environmental health of an ecosystem depends upon the health of its water supply. If a watershed is impaired, the health of its living inhabitants is compromised. Understanding the ecological interactions within an aquatic environment, and between a habitat and its inhabitants, aids in understanding how to better manage land and water resources. This is necessary for reaching a desperately needed equilibrium of ecosystem sustainability that currently does not exist.

Nonpoint source polluters, such as sediments and nutrients, are the cause of many water quality problems. Their sources are hard to identify, and they are hard to control without cooperation from private landholders and continual monitoring. Within waterways, they harm aquatic life, change the physical parameters, and create a more stagnant, sluggish, unhealthy system. Agriculture had been identified as a key producer of excess sediments and nutrients into adjoining waterways, due to livestock access, poor waste management, absence of riparian zones, and addition of nutrient rich fertilizers. As a result, systems for dealing with these issues have been developed.

Implementing Best Management Practices and establishing Total Maximum Daily Loads are starting points that will aid in reaching this sustainability. For example, additions of riparian zones to maintain cooler water temperatures and to keep stream banks from eroding is a good place to start when desiring to rehabilitate an impaired body of water. Developing standards for acceptable amounts of pollutants within a waterbody will aid in understanding how much of one pollutant an individual ecosystem can tolerate, resulting in more knowledgeable water monitoring practices and a better sense of how to modify problem areas. Watershed modeling also aids in the improvement of water quality by enabling simulation of natural systems to predict trends, anticipate problems, and to test the effectiveness of proposed implementations.

Benthic macroinvertebrates serve as good indicators of these problem areas, and are used by the state of Tennessee to delineate ecoregion reference stream criteria. They respond quickly to new environmental influences and a decrease in species diversity in these organisms can bring to attention a pollution input that otherwise may go unnoticed for a much longer period of time. Streams within Tennessee are classified as fully supporting, partially supporting, or non-supporting, depending on where their benthic score falls within its ecoregion criteria.

Water quality for both Nails and Ellejoy Creeks is considered impaired by state and federal standards. High amounts of sediments and nutrients are contributed to these streams from different kinds of landuse, but over 70% of sediment and nutrient inputs into streams in Blount County have been proven to come from agricultural practices. Landuse classification of both watersheds using GIS mapping software showed a high percentage of land within contributing areas to be pasture. Because of this, more and more interest has been shown by federal agencies, state agencies, and private landholders to improve protection of the water within this area. Water quality monitoring in this area for the purpose of this study showed that nutrient and sediment concentrations were higher than the reference stream values and need improvement.

Ellejoy Creek, as expected, was positively correlated among most sediment and nutrient variables, though due to limitations in sample size, it was not a significant correlation. There were no differences among sites, except for site 3 and site 6, which differed significantly in nitrate concentrations. Both of these sites are tributaries: site 3 is influenced by agricultural practices, and site 6 is not, exiting from heavily a forested area. These are expected differences, as landuse is a huge factor in nutrient concentrations. Benthic data from Ellejoy Creek was better than expected, indicating an increase in species diversity from previous years. Though some tributaries may be de-listed because of this, it is expected to remain on the upcoming 303(d) list.

Nails Creek was also positively correlated among sediment and nutrient variables, though not at a statistically significant level due to the sample size of the study. There were no differences among sites. Benthic collections were also better than anticipated, probably due to the amount of rainfall and the cool temperatures of the 2003 summer. It will remain on the 303(d) list. Though this is not a comparison study, it should be noted that the water quality of Nails Creek is much worse than Ellejoy Creek, contributing almost as many tonnes per year of sediments and nutrients as Ellejoy Creek, which is more than twice its size. This in part is due to the obvious lack of riparian zones and unrestricted livestock access. It also has twice as many residential areas as Ellejoy Creek. This may be of interest in future studies, because overall, the Nails Creek watershed is more residential in nature than is the Ellejoy Creek watershed.

Benthic and habitat data from both creeks, when statistically analyzed, showed that there were highly defined interactions between community and habitat variables. Nutrient tolerant species clustered in mass, while nutrient intolerant or independent species were few and scattered. This is as expected, as more than 70 % of the species collected from both streams were classified as nutrient tolerant. Environmental variables showed that bank stability and the presence of riparian zones were strongly correlated with the embeddedness of the substrate, riffle frequency, and benthic habitat, which makes sense physically. The benthic data from this stream indicates that benthic species diversity is strongly influenced by the presence of high amounts of nutrients, as the only species present in mass are nutrient tolerant.

Use of the model AQUATOX was not helpful to this study in simulating the next ten years in these watersheds, because there was no way within the model to account for landuse change. This area is anticipated to be mostly residential at the end of this time period, as development has increased dramatically over the past few years. Also, many of the parameters required to run the model were not measured in this study, resulting in heavy reliance of default values for stream simulation.

Often, phosphorus is overlooked in studies such as these. Because of its typically low levels, it is not considered a problem and concentrated with the general term nutrient. As stated previously, phosphorus has a longer retention time within soils than does nitrate, so usually this is used to explain lower levels of this nutrient. However, it is possible that phosphates are typically low because it is a limiting nutrient within the environment. Phosphorous levels were not high in data from this study, and it would be interesting to examine if this was because it is a limiting nutrient. There was not sufficient time or resources to examine phosphorus levels in greater detail for this study. A future study could make use of this data and determine the cause of low levels of phosphorus.

In summary, the data from this study has been given to TDEC and has contributed to the eventual development of TMDLs for these streams, which will ideally better the overall quality of each watershed, providing pollution loading standards to follow that does not yet exist. Studies such as this one will be the foundation for permit writing, fining, funding of BMP implementation, monitoring, and decision-making for watershed management all over the United States. As adequate, healthy water resources become more and more vital to supporting our growing population, individual watershed studies will be the key to acquiring and maintaining standards of better water quality.

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APPENDICES

APPENDIX A. TABLES

Table 1. Summary of Landuse for Ellejoy Creek Site 1 to Ellejoy Creek Site 2. (created from the TVA Little River IPSI data, 2002)

Landuse Description	Landuse Class	Number of Classes	Landuse Percentage
Residential	111	19	12.66
Row Crop w/residue	2102	2	1.14
Good Pasture, well maintained	212	2	3.64
Fair Pasture, min. maintenance	213	29	15.75
Heavily overgrazed pasture	215	9	2.53
Forest land	4	20	63.36
Water	5	14	1

For the buffer of site1 to site 2, the greatest percentages of landuse are in forest and fair pasture. There are also significant amounts of residential area.

Table 2. Summary of Landuse for Ellejoy Creek Site 2 to Ellejoy Creek Site 3. (created from the TVA Little River IPSI data, 2002)

Landuse Description	Landuse Class	Number of Classes	Landuse Percentage
Residential	111	19	15.71
Row Crop w/residue	2102	36	5.91
Good Pasture, well maintained	212	34	6.60
Fair Pasture, min. maintenance	213	98	45.15
Heavily overgrazed pasture	215	35	6.79
Forest land	4	123	18.78
Water	5	99	1.08

For the buffer of Ellejoy site 2 to Ellejoy site 3, the greatest percentage of landuse is fair pasture. Forest and residential are also high percentages.

Table 3. Summary of Landuse for Ellejoy Creek Site 2 to Ellejoy Creek Site 4. (created from the TVA Little River IPSI data, 2002)

Landuse Description	Landuse Class	Number of Classes	Landuse Percentage
Residential	111	8	8.79
Row Crop w/residue	2102	19	6.4
Good Pasture, well maintained	212	8	2.14
Fair Pasture, min. maintenance	213	62	22.43
Heavily overgrazed pasture	215	12	4.23
Forest land	4	58	55.06
Water	5	31	1

Table 3 shows the highest landuse percentage between site 2 and 4 to be in forest, followed by fair pasture and residential.

Table 4. Summary of Landuse for Ellejoy Creek Site 4 to Ellejoy Creek Site 5.
(created from the TVA Little River IPSI data, 2002)

Landuse Description	**Landuse Class**	**Number of Classes**	**Landuse Percentage**
Row Crop w/residue	2102	13	10.26
Good Pasture, well maintained	212	9	5.98
Fair Pasture, min. maintenance	213	34	45.58
Heavily overgrazed pasture	215	7	8.32
Forest land	4	49	27.33
Water	5	26	2.53

Between site 4 and 5, there is an abundance of fair pasture followed by forest.

Table 5. Summary of Landuse for Ellejoy Creek Site 4 to Ellejoy Creek Site 6.
(created from the TVA Little River IPSI data, 2002)

Landuse Description	**Landuse Class**	**Number of Classes**	**Landuse Percentage**
Residential	111	10	2.47
Row Crop w/residue	2102	7	3.04
Good Pasture, well maintained	212	6	1.03
Fair Pasture, min. maintenance	213	46	13.22
Heavily overgrazed pasture	215	10	1.87
Forest land	4	59	78.43

Table 5 shows that between site 4 and 6, there is mostly forest, followed by fair pasture. Site 6 is a tributary that connects just above site 4.

Table 6. Summary of Landuse for Ellejoy Creek Site 5 to Ellejoy Creek Site 7.
(created from the TVA Little River IPSI data, 2002)

Landuse Description	**Landuse Class**	**Number of Classes**	**Landuse Percentage**
Residential	111	10	9.33
Good Pasture, well maintained	212	15	2.75
Fair Pasture, min. maintenance	213	47	46.11
Heavily overgrazed pasture	215	25	8.11
Shrub and brush	32	7	1.84
Forest land	4	87	31.8

Table 6 shows site 7 connecting to site 5. Like site 6, site 7 is a tributary that meets the main stream just above site 5. Once again, the major landuses are fair pasture and forest.

Table 7. Summary of Landuse for Ellejoy Creek Site 5 to Ellejoy Creek Site 8.
(created from the TVA Little River IPSI data, 2002)

Landuse Description	Landuse Class	Number of Classes	Landuse Percentage
Residential	111	2	1.79
Row Crop, w/residue	2104	4	1.91
Fair Pasture, min. maintenance	213	23	25.15
Heavily overgrazed pasture	215	4	2.63
Forest land	4	30	68.56

Table 7 shows that site 8 is connected to site 6. The major landuses are forest and fair pasture.

Table 8. Summary of Landuse for Ellejoy Creek Site 8.
(created from the TVA Little River IPSI data, 2002)

Landuse Description	Landuse Class	Number of Classes	Landuse Percentage
Residential	111	6	3.28
Fair Pasture, min. maintenance	213	14	5.78
Heavily overgrazed pasture	215	5	2.48
Forest land	4	9	88.4

Table 8 sums the beginning of Ellejoy Creek. It is heavily forested.

Table 9. Summary of Landuse for Nails Creek Site 1 to Nails Creek Site 2.
(created from the TVA Little River IPSI data, 2002)

Landuse Description	Landuse Class	Number of Classes	Landuse Percentage
Residential	112	3	5.10
Row Crop w/residue	2102	7	6.70
Fair Pasture, min. maintenance	213	6	36.37
Heavily overgrazed pasture	215	3	26.81
Forest land	4	7	25.02

Table 9 begins at the mouth of Nails Creek.

Table 10. Summary of Landuse for Nails Creek Site 2 to Nails Creek Site 3.
(created from the TVA Little River IPSI data, 2002)

Landuse Description	Landuse Class	Number of Classes	Landuse Percentage
Residential	112	25	2.71
Row Crop w/residue	2102	16	6.52
Good Pasture, well maintained	212	17	2.31
Fair Pasture, min. maintenance	213	35	18.33
Heavily overgrazed pasture	215	26	2.93
Forest land	4	31	67.12
Water	5	20	1

Table 11. Summary of Landuse for Nails Creek Site 3 to Nails Creek Site 4.
(created from the TVA Little River IPSI data, 2002)

Landuse Description	Landuse Class	Number of Classes	Landuse Percentage
Residential	115	11	22.78
Row Crop w/residue	2101	9	3.69
Good Pasture, well maintained	212	7	2.35
Fair Pasture, min. maintenance	213	50	28.09
Heavily overgrazed pasture	215	18	8.77
Forest land	4	65	34.32

Table 11 shows that between NC3 and NC4, fair pasture, forestland, and residences are the major landuses.

Table 12. Summary of Landuse for Nails Creek Site 4.
(created from the TVA Little River IPSI data, 2002)

Landuse Description	Landuse Class	Number of Classes	Landuse Percentage
Residential	115	2	49.05
Fair Pasture, min. maintenance	213	17	25.32
Heavily overgrazed pasture	215	3	2.71
Forest land	4	27	23.27

Table 12 is the final landuse by percentage table for all the sites. It is the most highly residential of the sites, and is followed by fair pastureland.

Table 13. Summary of the Major Landuses Contributing to each Sample Site.
(created from the TVA Little River IPSI data, 2002)

Site	Percent Forest Land	Percent Fair Pasture, minimum maintenance	Percent Residences, low density
EJ1	52.44	27.34	2.83
EJ2	51.08	29.00	2.07
EJ3	45.15	17.66	7.38
EJ4	57.71	27.08	1.43
EJ5	46.29	19.15	1.78
EJ6	77.57	13.22	1.84
EJ7	46.11	31.31	4.50
EJ8	87.95	5.44	2.63
NC1	35.38	26.85	13.70
NC2	38.95	23.70	18.26
NC3	25.035	26.38	27.39
NC4	22.59	24.67	38.6

Table 13 is a summary of the three major landuse classes for the entire contributing area for each site on both streams.

Table 14. Summary of the Livestock Sites between each Sample Site. (Note: "Livestock" refers to horses, beef, and dairy cattle. There can be more than one livestock site per farm.)
(created from the TVA Little River IPSI data, 2002)

Location	Number of Total Livestock Operations	Horse Operations	Cow Operations	Size
EJ1 to EJ2	11	4	7	S/M
EJ2 to EJ3	43	8	35	S/M
EJ2 to EJ4	12	6	6	S/M
EJ4 to EJ5	5	0	5	S/M
EJ4 to EJ6	9	0	9	S/M
EJ5 to EJ7	37	6	31	S/M
EJ5 to EJ8	1	0	1	S/M
EJ8	5	0	5	S/M
NC1 to NC2	22	1	21	S/M
NC2 to NC3	24	1	23	S/M
NC3 to NC4	20	6	14	S/M
NC4	4	0	4	S/M

Table 14 shows the livestock sites, type of livestock, and size of the livestock operations for each buffered area. "Small" means 25 head of beef or dairy livestock, and 5 horses. "Medium" means 50 head of beef or dairy livestock, and 10 horses.

Table 15. Summary of the Livestock in Contributing Areas between each Sample Site.
(created from the TVA Little River IPSI data, 2002)

Location	Number of Total Livestock Operations	Horse Operations	Cow Operations	Size
EJ1	193	32	161	S/M
EJ2	182	28	154	S/M
EJ3	29	7	22	S/M
EJ4	52	6	46	S/M
EJ5	43	6	37	S/M
EJ6	8	0	8	S/M
EJ7	25	5	20	S/M
EJ8	5	0	5	S/M
NC1	70	8	62	S/M
NC2	48	7	41	S/M
NC3	24	6	18	S/M
NC4	4	0	4	S/M

Table 15 shows a breakdown of the livestock sites for each contributing area for each sample site. The numbers were obtained from a simple subtraction, starting with a livestock total at the mouth of each stream.

Table 16. General Linear Mean Procedure, Total Kjedahl Nitrogen.

		Total Kjedahl Nitrogen (mg/L)			
Stream by Site		**Mean**	**Std Dev**	**Minimum**	**Maximum**
Ellejoy	**1**	0.34	0.22	0.02	0.74
	2	0.38	0.25	0.13	0.96
	3	0.37	0.31	0.12	1.13
	4	0.41	0.36	0.03	1.30
	5	0.39	0.30	0.15	1.21
	6	0.24	0.08	0.07	0.37
	7	0.36	0.21	0.08	0.72
	8	0.30	0.29	0.05	1.09
	All Sites	0.35	0.26	0.02	1.30
Nails	**1**	0.30	0.15	0.11	0.56
	2	0.30	0.14	0.12	0.50
	3	0.26	0.16	0.05	0.55
	4	0.18	0.09	0.09	0.39
	All Sites	0.26	0.14	0.05	0.56
Reference	**1**	0.09	.	0.09	0.09
	All Sites	0.09	.	0.09	0.09

Table 17. General Linear Mean Procedure, Ammonia-N.

Stream by Site		Ammonia-N (mg/L) Mean	Std Dev	Minimum	Maximum
Ellejoy	**1**	0.23	0.20	0.04	0.67
	2	0.21	0.16	0.04	0.56
	3	0.19	0.11	0.04	0.34
	4	0.18	0.16	0.02	0.55
	5	0.19	0.18	0.01	0.53
	6	0.10	0.13	0.01	0.48
	7	0.13	0.13	0.00	0.42
	8	0.07	0.06	0.01	0.19
	All Sites	0.16	0.15	0.00	0.67
Nails	**1**	0.18	0.21	0.02	0.57
	2	0.14	0.13	0.03	0.41
	3	0.16	0.13	0.03	0.36
	4	0.08	0.03	0.04	0.14
	All Sites	0.14	0.14	0.02	0.57
Reference	**1**	0.01	.	0.01	0.01
	All Sites	0.01	.	0.01	0.01

Table 18. General Linear Mean Procedure, Nitrate-N.

Stream by Site		Nitrate-N (mg/L) Mean	Std Dev	Minimum	Maximum
Ellejoy	1	2.43	1.28	0.32	4.58
	2	2.47	1.26	0.48	4.63
	3	4.05	1.67	0.84	5.88
	4	2.04	1.38	0.11	5.05
	5	2.44	1.41	0.29	4.45
	6	1.71	1.63	0.00	4.34
	7	3.31	2.03	0.67	6.19
	8	2.17	2.18	0.08	6.89
	All Sites	2.59	1.71	0.00	6.89
Nails	1	3.00	2.08	0.38	6.69
	2	3.25	1.90	0.50	5.93
	3	3.64	1.51	0.81	5.22
	4	3.29	1.57	0.70	4.88
	All Sites	3.30	1.73	0.38	6.69
Reference	1	0.90	.	0.90	0.90
	All Sites	0.90	.	0.90	0.90

Table 19. General Linear Mean Procedure, Total Phosphorous.

Stream by Site		Mean	Std Dev	Minimum	Maximum
		Total Phosphorus (mg/L)			
Ellejoy	**1**	0.09	0.07	0.02	0.21
	2	0.08	0.05	0.02	0.18
	3	0.07	0.04	0.02	0.17
	4	0.10	0.06	0.03	0.24
	5	0.07	0.05	0.02	0.17
	6	0.07	0.04	0.02	0.15
	7	0.07	0.04	0.02	0.17
	8	0.06	0.04	0.02	0.16
	All Sites	0.08	0.05	0.02	0.24
Nails	**1**	0.07	0.05	0.02	0.17
	2	0.07	0.04	0.03	0.16
	3	0.07	0.04	0.02	0.16
	4	0.06	0.04	0.02	0.15
	All Sites	0.07	0.04	0.02	0.17
Reference	**1**	0.05	.	0.05	0.05
	All Sites	0.05	.	0.05	0.05

Table 20. General Linear Mean Procedure, Orthophosphate.

Stream by Site		Orthophosphate (mg/L) Mean	Std Dev	Minimum	Maximum
Ellejoy	1	0.02	0.02	0.00	0.07
	2	0.02	0.01	0.00	0.06
	3	0.02	0.01	0.01	0.05
	4	0.03	0.02	0.01	0.01
	5	0.02	0.01	0.01	0.07
	6	0.02	0.02	0.03	0.08
	7	0.02	0.01	0.00	0.06
	8	0.02	0.02	0.00	0.07
	All Sites	0.02	0.02	0.00	0.08
Nails	1	0.02	0.02	0.01	0.07
	2	0.02	0.01	0.01	0.06
	3	0.02	0.01	0.01	0.06
	4	0.01	0.01	0.01	0.06
	All Sites	0.02	0.01	0.01	0.07
Reference	1	.	.	.	.
	All Sites	.	.	.	.

Table 21. General Linear Mean Procedure, Total Suspended Solids.

Stream by Site		Total Suspended Solids (mg/L) Mean	Std Dev	Minimum	Maximum
Ellejoy	1	0.40	0.48	0.04	1.66
	2	0.40	0.34	0.00	1.15
	3	0.43	0.25	0.06	0.91
	4	0.69	1.38	0.01	4.88
	5	0.27	0.22	0.01	0.81
	6	0.20	0.17	0.01	0.55
	7	0.26	0.18	0.01	0.60
	8	0.24	0.21	0.02	0.60
	All Sites	0.36	0.55	0.00	4.88
Nails	1	0.61	0.62	0.04	2.31
	2	0.43	0.47	0.04	1.72
	3	0.46	0.32	0.14	1.13
	4	0.40	0.41	0.15	1.64
	All Sites	0.47	0.46	0.04	2.31
Reference	1	5.00	.	5.00	5.00
	All Sites	5.00	.	5.00	5.00

Table 22. General Linear Mean Procedure, Total Dissolved Solids.

Stream by Site		Total Dissolved Solids (mg/L)			
		Mean	Std Dev	Minimum	Maximum
Ellejoy	1	253	128	159	642
	2	228	74	149	358
	3	264	81	205	444
	4	198	52	131	321
	5	255	154	137	719
	6	147	80	62	363
	7	259	56	205	424
	8	224	354	75	1343
	All Sites	229	153	62	1343
Nails	1	246	52	186	370
	2	236	89	57	453
	3	239	33	201	327
	4	239	28	196	284
	All Sites	240	54	57	453
Reference	1	170	.	170	170
	All Sites	170	.	170	170

Table 23. General Linear Mean Procedure, Total Solids.

Stream by Site		Total Solids (mg/L) Mean	Std Dev	Minimum	Maximum
Ellejoy	**1**	253	128	159	642
	2	228	74	149	358
	3	264	81	206	444
	4	198	52	132	322
	5	255	154	138	720
	6	147	80	62	364
	7	259	56	205	424
	8	224	354	76	1344
	All Sites	229	153	62	1344
Nails	**1**	246	52	186	370
	2	236	89	57	453
	3	239	33	201	327
	4	239	28	196	284
	All Sites	240	54	57	453
Reference	**1**	.	.	.	.
	All Sites	.	.	.	.

Table 24. General Linear Mean Procedure, Biochemical Oxygen Demand.

		Biochemical Oxygen Demand (mg/L)			
Stream by Site		Mean	Std Dev	Minimum	Maximum
Ellejoy	1	1.95	1.24	0.06	4.51
	2	2.34	1.34	0.42	4.68
	3	2.24	1.23	0.78	4.14
	4	2.67	1.76	0.50	5.65
	5	2.11	1.34	0.59	4.62
	6	2.23	1.59	0.86	5.80
	7	2.07	1.49	0.52	5.60
	8	2.00	1.40	0.74	4.93
	All Sites	2.20	1.39	0.06	5.80
Nails	1	2.64	1.64	0.55	5.39
	2	2.28	1.34	0.87	4.81
	3	1.87	1.22	0.70	4.14
	4	2.09	1.49	0.51	5.19
	All Sites	2.22	1.41	0.51	5.39
Reference	1	.	.	.	.
	All Sites	.	.	.	.

Table 25. General Linear Mean Procedure, Dissolved Oxygen.

Stream by Site		Dissolved Oxygen (mg/L) Mean	Std Dev	Minimum	Maximum
Ellejoy	**1**	9.81	1.81	7.60	13
	2	8.45	1.89	5.27	12
	3	9.28	0.93	7.93	10
	4	9.85	1.86	7.85	12
	5	10	1.69	7.96	12
	6	10	1.75	8.21	13
	7	9.16	1.47	7.32	11
	8	9.97	1.91	7.76	13
	All Sites	9.60	1.71	5.27	13
Nails	**1**	11	2.50	8.68	16
	2	10	1.26	8.59	11
	3	10	1.17	8.77	11
	4	9.16	0.92	8.24	10
	All Sites	10	1.69	8.24	16
Reference	**1**	.	.	.	.
	All Sites	.	.	.	.

Table 26. General Linear Mean Procedure, pH.

Stream by Site		pH Mean	Std Dev	Minimum	Maximum
	1	8.20	0.43	7.62	9.09
	2	8.20	0.55	7.52	9.22
	3	8.05	0.40	7.55	9.00
	4	8.07	0.51	7.01	8.98
	5	7.97	0.37	7.28	8.52
	6	8.01	0.44	7.46	8.65
	7	7.89	0.45	6.76	8.46
	8	7.97	0.57	6.58	8.62
Ellejoy	All Sites	8.05	0.46	6.58	9.22
	1	8.20	0.37	7.76	8.86
	2	8.12	0.53	7.18	9.09
	3	8.14	0.53	6.90	9.00
	4	7.92	0.65	6.47	8.89
Nails	All Sites	8.09	0.52	6.47	9.09
	1	.	.	.	.
Reference	All Sites	.	.	.	.

Table 27. General Linear Mean Procedure, Total Kjedahl Nitrogen (metric tons/yr).

		Total Kjedahl Nitrogen (tonnes/year)			
Stream by Site		**Mean**	**Std Dev**	**Minimum**	**Maximum**
	1	9.04	17	0.40	58
	2	7.60	15	0.05	47
	3	2.40	4.23	0.00	13
	4	5.34	9.93	0.01	33
	5	4.69	10	0.00	34
	6	0.77	0.87	0.00	2.37
	7	1.05	1.82	0.00	5.71
	8	0.35	0.33	0.00	0.93
Ellejoy	**All Sites**	3.92	9.88	0.00	58
	1	4.76	7.56	0.27	24
	2	4.13	6.22	0.03	18
	3	2.04	2.92	0.00	8.66
	4	0.27	0.31	0.00	0.85
Nails	**All Sites**	2.85	5.29	0.00	24
	1	.	.	.	.
Reference	**All Sites**	.	.	.	.

Table 28. General Linear Mean Procedure, Ammonia-N (metric tons/yr).

		Ammonia-N (tonnes/year)			
Stream by Site		**Mean**	**Std Dev**	**Minimum**	**Maximum**
	1	7.49	15	0.08	52
	2	4.51	8.86	0.02	27
	3	0.92	1.27	0.01	3.97
	4	2.88	6.02	0.01	19
	5	1.76	4.16	0.00	12
	6	0.18	0.25	0.00	0.82
	7	0.57	0.89	0.00	2.30
	8	0.20	0.26	0.00	0.67
Ellejoy	**All Sites**	2.36	7.20	0.00	52
	1	3.71	7.93	0.10	24
	2	2.88	6.13	0.01	17
	3	1.03	1.75	0.00	5.30
	4	0.12	0.11	0.00	0.33
Nails	**All Sites**	1.99	5.17	0.00	24
	1	.	.	.	.
Reference	**All Sites**	.	.	.	.

Table 29. General Linear Mean Procedure, Nitrate-N (metric tons/yr).

Stream by Site		Nitrate-N (tonnes/year) Mean	Std Dev	Minimum	Maximum
	1	52	62	0.64	178
	2	39	46	0.25	128
	3	17	16	0.02	41
	4	28	47	0.04	153
	5	14	17	0.03	48
	6	4.17	6.59	0.00	21
	7	8.58	10	0.00	28
	8	4.63	10	0.00	31
Ellejoy	**All Sites**	21	36	0.00	178
	1	39	51	0.32	141
	2	47	56	0.19	143
	3	27	30	0.02	92
	4	7.83	7.83	0.01	22
Nails	**All Sites**	30	41	0.01	143
	1	.	.	.	.
Reference	**All Sites**	.	.	.	.

Table 30. General Linear Mean Procedure, Total Phosphorous (metric tons/yr).

		Total Phosphorus (tonnes/year)			
Stream by Site		**Mean**	**Std Dev**	**Minimum**	**Maximum**
	1	2.38	4.81	0.08	16
	2	1.35	2.17	0.01	7.49
	3	0.32	0.44	0.00	1.49
	4	0.98	1.60	0.00	5.58
	5	0.50	0.80	0.00	2.79
	6	0.20	0.21	0.00	0.53
	7	0.19	0.25	0.00	0.80
	8	0.12	0.11	0.00	0.30
Ellejoy	**All Sites**	0.76	2.03	0.00	16
	1	1.21	2.14	0.11	7.49
	2	0.84	1.17	0.01	4.04
	3	0.42	0.44	0.00	1.34
	4	0.08	0.09	0.00	0.29
Nails	**All Sites**	0.64	1.27	0.00	7.49
	1	.	.	.	.
Reference	**All Sites**	.	.	.	.

Table 31. General Linear Mean Procedure, Orthophosphate (metric tons/yr).

Stream by Site		Orthophosphate (tonnes/year) Mean	Std Dev	Minimum	Maximum
	1	0.79	1.66	0.01	5.71
	2	0.48	0.79	0.00	2.68
	3	0.08	0.08	0.00	0.24
	4	0.32	0.54	0.00	1.87
	5	0.17	0.28	0.00	0.99
	6	0.04	0.04	0.00	0.14
	7	0.06	0.07	0.00	0.19
	8	0.03	0.03	0.00	0.10
Ellejoy	All Sites	0.25	0.71	0.00	5.71
	1	0.48	0.90	0.02	3.13
	2	0.32	0.51	0.00	1.78
	3	0.12	0.12	0.00	0.34
	4	0.02	0.03	0.00	0.07
Nails	All Sites	0.24	0.53	0.00	3.13
	1	.	.	.	.
Reference	All Sites	.	.	.	.

Table 32. General Linear Mean Procedure, Total Suspended Solids (metric tons/yr).

Stream by Site		Mean	Std Dev	Minimum	Maximum
		Total Suspended Solids (tonnes/year)			
	1	8.96	11	0.08	27
	2	8.72	9.94	0.00	26
	3	1.68	1.55	0.00	3.72
	4	3.33	3.79	0.00	10
	5	2.40	3.33	0.00	9.35
	6	1.08	1.52	0.00	4.59
	7	0.75	0.86	0.00	2.47
	8	0.41	0.65	0.00	2.16
Ellejoy	All Sites	3.42	6.33	0.00	27
	1	10	13	0.09	36
	2	6.09	8.29	0.03	21
	3	2.89	2.86	0.00	8.25
	4	0.78	1.19	0.00	4.19
Nails	All Sites	4.95	8.49	0.00	36
	1	.	.	.	.
Reference	All Sites	.	.	.	.

Table 33. General Linear Mean Procedure, Total Dissolved Solids (metric tons/yr).

Stream by Site		Total Dissolved Solids (tonnes/year) Mean	Std Dev	Minimum	Maximum
	1	5924	6960	328	18072
	2	3657	4586	31	12757
	3	1086	1211	2.46	3689
	4	2208	2983	4.38	8376
	5	1709	1951	1.55	5611
	6	453	487	0.51	1299
	7	768	789	0.82	1970
	8	261	218	0.08	570
Ellejoy	All Sites	2008	3607	0.08	18072
	1	3401	3845	212	11536
	2	3037	3446	18.32	10011
	3	1613	1735	1.55	4606
	4	428	384	0.33	1214
Nails	All Sites	2120	2892	0.33	11536
	1	.	.	.	.
Reference	All Sites	.	.	.	.

Table 34. General Linear Mean Procedure, Total Solids (metric tons/yr).

Stream by Site		Total Solids (tonnes/year)			
		Mean	**Std Dev**	**Minimum**	**Maximum**
Ellejoy	**1**	5924	6961	328	18074
	2	3657	4586	31	12757
	3	1087	1211	2.46	3690
	4	2208	2983	4.38	8376
	5	1709	1951	1.55	5611
	6	453	487	0.51	1299
	7	768	789	0.82	1970
	8	261	218	0.08	570
	All Sites	2009	3607	0.08	18074
Nails	**1**	3401	3846	212	11539
	2	3038	3446	18	10013
	3	1613	1735	1.55	4606
	4	428	384	0.33	1214
	All Sites	2120	2893	0.33	11539
Reference	**1**	.	.	.	.
	All Sites	.	.	.	.

Table 35. Ellejoy Creek Sediment Distribution Statistics.

			Distribution Statistics			
Variable	**N**	**Mean**	**Std Dev**	**Sum**	**Minimum**	**Maximum**
TS	96	229	153	21997	62	1344
TDS	96	229	153	21996	62	1344
TSS	96	0.36	0.55	34	0	4.88

Table 36. Ellejoy Creek Sediment Correlation.

Pearson Correlation Coefficients, N = 96
Prob > |r| under H0: Rho=0

	TS	**TDS**	**TSS**
TS		1.00 <.01	0.07 0.45
TDS	1.00 <.01		0.07 0.45
TSS	0.07 0.45	0.07 0.45	

Table 37. Ellejoy Creek Nutrient Distribution Statistics.

			Distribution Statistics			
Variable	**N**	**Mean**	**Std Dev**	**Sum**	**Minimum**	**Maximum**
TP	96	0.08	0.05	7.68	0.02	0.24
PO4	95	0.02	0.02	2.28	0	0.08
TKN	89	0.35	0.26	31	0.02	1.30
NO3	92	2.59	1.71	238	0	6.89
NH3	83	0.16	0.15	13	0	0.67

Table 38. Ellejoy Creek Nutrient Correlation.

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	TP	PO4	TKN	NO3	NH3
TP		0.58 <.01 95	0.54 <.01 89	-0.27 0.01 92	0.52 <.01 83
PO4	0.58 <.01 95		0.50 <.01 88	-0.44 <.01 91	0.67 <.01 82
TKN	0.54 <.01 89	0.50 <.01 88		-0.03 0.75 86	0.56 <.01 81
NO3	-0.27 0.01 92	-0.44 <.01 91	-0.03 0.75 86		-0.06 0.53 82
NH3	0.52 <.01 83	0.67 <.01 82	0.56 <.01 81	-0.06 0.53 82	

Table 39. Ellejoy Creek Sediment and Nutrient Distribution Statistics.

Distribution Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
TP	96	0.08	0.05	7.68	0.02	0.24
PO4	95	0.02	0.02	2.28	0	0.08
TKN	89	0.35	0.26	31	0.02	1.30
NO3	92	2.59	1.71	238	0	6.89
NH3	83	0.16	0.15	13	0	0.67
TS	96	229	153	21997	62	1344
TDS	96	229	153	21996	62	1344
TSS	96	0.36	0.55	34	0	4.88

Table 40. Ellejoy Creek Sediment and Nutrient Correlation.

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	TS	TDS	TSS
TP	0.04 0.68 96	0.04 0.68 96	-0.03 0.75 96
PO4	-0.05 0.58 95	-0.05 0.58 95	-0.20 0.04 95
TKN	0.29 0.04 89	0.29 0.04 89	-0.12 0.26 89
NO3	0.29 0.04 92	0.29 0.04 92	0.08 0.43 92
NH3	-0.01 0.87 83	-0.07 0.87 83	-0.13 0.22 83

Table 41. Ellejoy Creek Sediment and Nutrient Distribution Statistics (metric tons/yr).

Distribution Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
TKN	81	3.92	9.88	318	0.00	58
NH3	75	2.36	7.20	177	0.00	52
NO3	84	21	36	1844	0	178
TSS	88	3.42	6.33	301	0	27
TDS	88	2009	3607	176784	0.08	18073
TS	88	2009	3608	176794	0.08	18075
TP	88	0.76	2.03	66	0.00	16
PO4	87	0.25	0.71	22	0.00	5.71

Table 42. Ellejoy Creek Sediment and Nutrient Correlation (metric tons/yr).

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	TKN	NH3	NO3	TSS	TDS	TS	TP	PO4
TKN		0.94 <.01 73	0.55 <.01 78	0.42 <.01 81	0.76 <.01 81	0.76 <.01 81	0.91 <.01 81	0.92 <.01 80
NH3	0.94 <.01 73		0.44 <.01 74	0.28 0.01 75	0.67 <.01 75	0.67 <.01 75	0.98 <.01 75	0.98 <.01 74
NO3	0.55 <.01 78	0.44 <.01 74		0.73 <.01 84	0.82 <.01 84	0.82 <.01 84	0.49 <.01 84	0.53 <.01 83
TSS	0.42 <.01 81	0.28 0.01 75	0.73 <.01 84		0.74 <.01 88	0.74 <.01 88	0.33 0.01 88	0.32 0.01 87
TDS	0.76 <.01 81	0.67 <.01 75	0.82 <.01 84	0.74 <.01 88		1.00 <.01 88	0.71 <.01 88	0.72 <.01 87
TS	0.76 <.01 81	0.67 <.01 75	0.82 <.01 84	0.74 <.01 88	1.00 <.01 88		0.71 <.01 88	0.72 <.01 87
TP	0.91 <.01 81	0.98 <.01 75	0.49 <.01 84	0.33 0.01 88	0.71 <.01 88	0.71 <.01 88		0.98 <.01 87
PO4	0.92 <.01 80	0.98 <.01 74	0.53 <.01 83	0.32 0.01 87	0.72 <.01 87	0.72 <.01 87	0.98 <.01 87	

Table 43. Nails Creek Sediment Distribution Statistics.

Distribution Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
TS	48	240	54	11540	57	453
TDS	48	240	54	11540	57	453
TSS	48	0.47	0.46	22	0.04	2.31

Table 44. Nails Creek Sediment Correlation.

	Pearson Correlation Coefficients, N = 48 Prob > |r| under H0: Rho=0		
	TS	**TDS**	**TSS**
TS		1.00 <.01	0.07 0.60
TDS	1.00 <.01		0.07 0.60
TSS	0.07 0.60	0.07 0.60	

Table 45. Nails Creek Nutrient Distribution Statistics.

Distribution Statistics						
Variable	**N**	**Mean**	**Std Dev**	**Sum**	**Minimum**	**Maximum**
TP	48	0.07	0.04	3.45	0.02	0.17
PO4	48	0.02	0.01	1.13	0.01	0.07
TKN	40	0.26	0.14	10	0.05	0.56
NO3	46	3.30	1.72	152	0.38	6.69
NH3	37	0.14	0.14	5.34	0.02	0.57

Table 46. Nails Creek Nutrient Correlation.

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	TP	**PO4**	**TKN**	**NO3**	**NH3**
TP		0.34 0.01 48	0.55 0.01 40	-0.16 0.26 46	0.35 0.03 37
PO4	0.34 0.01 48	.	0.25 0.10	-0.49 0.01 46	0.56 0.01 37
TKN	0.55 0.01 40	0.25 0.10 40		-0.25 0.11 40	0.49 0.01 34
NO3	-0.16 0.26 46	-0.49 0.04 46	-0.25 0.11 40		0.05 0.75 37
NH3	0.35 0.03 37	0.56 0.03 37	0.49 0.03 34	0.05 0.75 37	

Table 47. Nails Creek Sediment and Nutrient Distribution Statistics.

Distribution Statistics

Variable	**N**	**Mean**	**Std Dev**	**Sum**	**Minimum**	**Maximum**
TP	48	0.07	0.04	3.45	0.02	0.17
PO4	48	0.02	0.01	1.13	0.06	0.07
TKN	40	0.26	0.14	10	0.05	0.56
NO3	46	3.30	1.72	152	0.38	6.69
NH3	37	0.14	0.14	5.34	0.02	0.57
TS	48	240	54	11540	57	453
TDS	48	240	54	11540	57	453
TSS	48	0.47	0.46	22	0.04	2.31

Table 48. Nails Creek Sediment and Nutrient Correlation.

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	TS	**TDS**	**TSS**
TP	0.26 0.06 48	0.26 0.06 48	-0.05 0.70 48
PO4	-0.17 0.22 48	-0.17 0.22 48	-0.21 0.14 48
TKN	0.03 0.85 40	0.03 0.85 40	-0.01 0.95 40
NO3	0.14 0.35 46	0.14 0.35 46	0.13 0.38 46
NH3	0.05 0.76 37	0.05 0.76 37	-0.17 0.30 37

Table 49. Nails Creek Sediment and Nutrient Distribution Statistics (metric tons/yr).

Distribution Statistics

Variable	**N**	**Mean**	**Std Dev**	**Sum**	**Minimum**	**Maximum**
TKN	37	2.85	5.29	105	0.01	24
NH3	33	1.99	5.17	65	0.01	24
NO3	42	30	41	1262	0.04	143
TSS	44	4.95	8.49	217	0.01	36
TDS	44	2120	2893	93290	0.33	11537
TS	44	2120	2893	93298	0.33	11539
TP	44	0.64	1.27	28	0.01	7.49
PO4	44	0.23	0.53	10	0.01	3.13

Table 50. Nails Creek Sediment and Nutrient Correlation (metric tons/yr).

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	TKN	**NH3**	**NO3**	**TSS**	**TDS**	**TS**	**TP**	**PO4**
TKN		0.94 <.01 31	0.85 <.01 37	0.78 <.01 37	0.90 <.01 37	0.90 <.01 37	0.95 <.01 37	0.94 <.01 37
NH3	0.94 <.01 31		0.67 <.01 33	0.67 <.01 33	0.74 <.01 33	0.74 <.01 33	0.96 <.01 33	0.96 <.01 33
NO3	0.85 <.01 37	0.67 <.01 33		0.78 <.01 42	0.93 <.01 42	0.93 <.01 42	0.76 <.01 42	0.73 <.01 42
TSS	0.78 <.01 37	0.67 <.01 33	0.78 <.01 42		0.69 <.01 44	0.69 <.01 44	0.57 <.01 44	0.58 <.01 44
TDS	0.90 <.01 37	0.74 <.01 33	0.93 <.01 42	0.69 <.01 44		1.00 <.01 44	0.83 <.01 44	0.81 <.01 44
TS	0.90 <.01 37	0.74 <.01 33	0.93 <.01 42	0.69 <.01 44	1.00 <.01 44		0.83 <.01 44	0.81 <.01 44
TP	0.95 <.01 37	0.96 <.01 33	0.76 <.01 42	0.57 <.01 44	0.83 <.01 44	0.83 <.01 44		0.98 <.01 44
PO4	0.94 <.01 37	0.96 <.01 33	0.73 <.01 42	0.58 <.01 44	0.81 <.01 44	0.81 <.01 44	0.98 <.01 44	

Table 51. Ellejoy Creek Nitrate-N Mean Separation Test.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**	**R-Square**	**Coeff Var**	**Root MSE**	**NO3 Mean**
Model	7	45	6.55	2.49	0.02	0.17	62	1.62	2.59
Error	84	220	2.62						
Corrected Total	91	266							

Table 52. Ellejoy Creek Nitrate-N Mean Separation Error.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	7	45	6.55	2.49	0.02

Table 53. Ellejoy Creek Nitrate-N Tukey's Studentized Range Test.
(alpha=0.05, Error DF =84, Error Mean square=2.62, Critical value=4.39, minimum significant difference=2.10)

Means with the same letter are not significantly different.

Tukey Grouping		Mean	N	Site
	A	4.05	12	EC3
	A			
B	A	3.31	11	EC7
B	A			
B	A	2.47	12	EC2
B	A			
B	A	2.44	12	EC5
B	A			
B	A	2.43	12	EC1
B	A			
B	A	2.17	10	EC8
B	A			
B	A	2.04	12	EC4
B				
B		1.71	11	EC6

Table 54. Habitat Parameters for Assigning a Habitat Assessment Score.
(modified from TDEC state parameters, TDEC, 2003a)

Habitat Parameter	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/Available Cover	> 70% substrate good colonization	40-70% stability well-suited	20-40% stability less than desirable	< 20% stability
2. Embeddedness	Particles 0-25% surrounded by fine sediment.	Particles 25-50% surrounded by fine sediment.	Particles 50-75% surrounded by fine sediment.	> 76% surrounded
3. Velocity/Depth Regime	4 velocity/depth regimes present	3 regimes present	2 regimes present	1 regime present
4. Sediment Deposition	Point bars < 5%	Point bars < 5-30%	Point bars < 50-80%	Point bars > 80
5. Channel Flow Status	Water reaches base of both lower banks	Water fills> 75%	Waters fills 25-75 %	Very little water
6. Channel Alteration	Absent	None recent	Extensive >40%	>80%
7. Frequency of Riffles (or bends)	Frequent	Infrequent	Occasional	Few or None
8. Bank Stability	Banks stable	Moderately stable	Moderately unstable	Unstable
9. Vegetative Protective (score	> 90%	70-90%	50-70%	< 50%
10. Riparian Vegetative Zone Width (score each	> 18 meters	12-18 meters	6-12 meters	<6 meters

Table 55. Principle Component Analysis for Environmental Variables across all Sites and Samples.

		Eigenvalues		
		Individual	Cumulative	
No.	Eigenvalue	Percent	Percent	Scree Plot
1	10	49	48	||||||||||
2	5	25	73	|||||
3	2	8	81	||

80.6 % of the variance between landuse can be explained by landuse alteration, such as removal of Riparian Zones, Bank Erosion, and absence of Bank Vegetation.

Table 56. Principle Component Analysis for Species Variables across all Sites and Samples.

		Eigenvalues		
		Individual	Cumulative	
No.	Eigenvalue	Percent	Percent	Scree Plot
1	6	24	24	|||||
2	5	21	45	|||||
3	2	9	55	||

54.7 % of the variance among species can be explained by tolerance and intolerance to nutrients.

Table 57. Intolerant Macroinvertebrate Families for Tennessee and Nutrient Intolerant Species Found in Nails and Ellejoy Creeks, Separated from the Majority.

Intolerant Macroinvertebrate Families for Bioregions (Based on average genus NCBI scores for Tennessee taxa within families)					
Common Name	Mayflies	Stoneflies	Caddisflies	Beetles	Flies
Family	Ephemeroptera	Plecoptera	Trichoptera	Coleoptera	Diptera
Species	Baetidae		Hydropschidae	Optioservus	Simulium
	Stenomema		Cheumatopsyche	Dubiraphia	
	Gomphidae			Stenelmis	
	Isonychiidae				

Table 58. Sediment and Nutrient Loadings from Nails and Ellejoy Creeks.

Stream	TKN	NH3	NO3	TP	PO4	TSS	TDS	TS
EC	3.92	2.36	21	0.76	0.25	3.42	2008	2009
NC	2.85	1.99	30	0.64	0.24	4.95	2120	2120

Table 59. Sediment and Nutrient Values from Nails, Ellejoy, and the Reference Stream.

Stream	TKN	NH3	NO3	TP	TSS	TDS
EC	0.35	0.16	2.59	0.08	3.42	229
NC	0.26	0.14	3.30	0.07	4.95	240
Ref	0.09	0.01	0.9	0.05	5	170

APPENDIX B. FIGURES

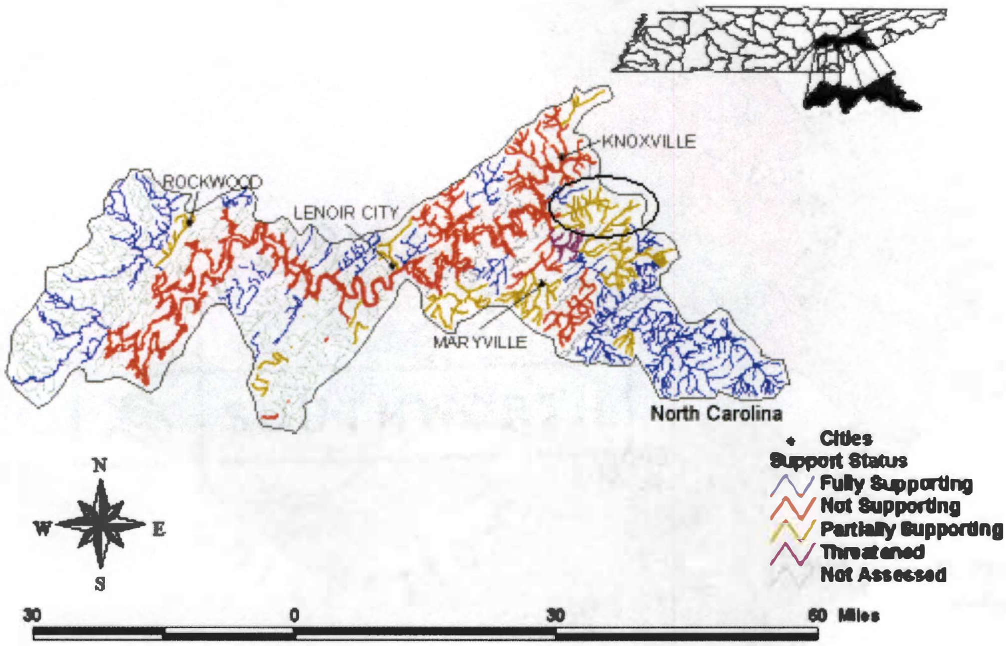


Figure 1. Watts Bar Lake Watershed (HUC8, 06010201).
The circle indicates the approximate location of Nails and Ellejoy Creeks.
Source: Tennessee Department of Environment and Conservation, Water Quality Use Support Summary Maps, 2002.

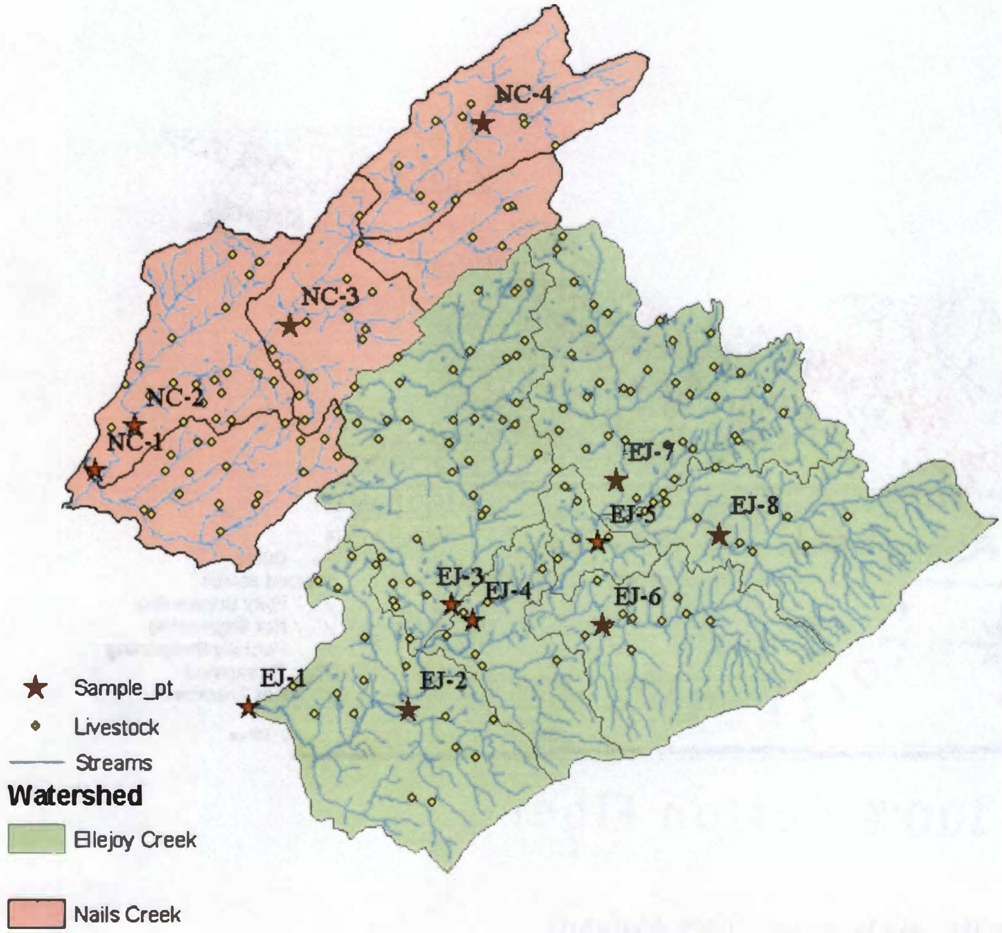


Figure 2. Nails and Ellejoy Creeks watershed delineations, with sample sites and livestock operations.

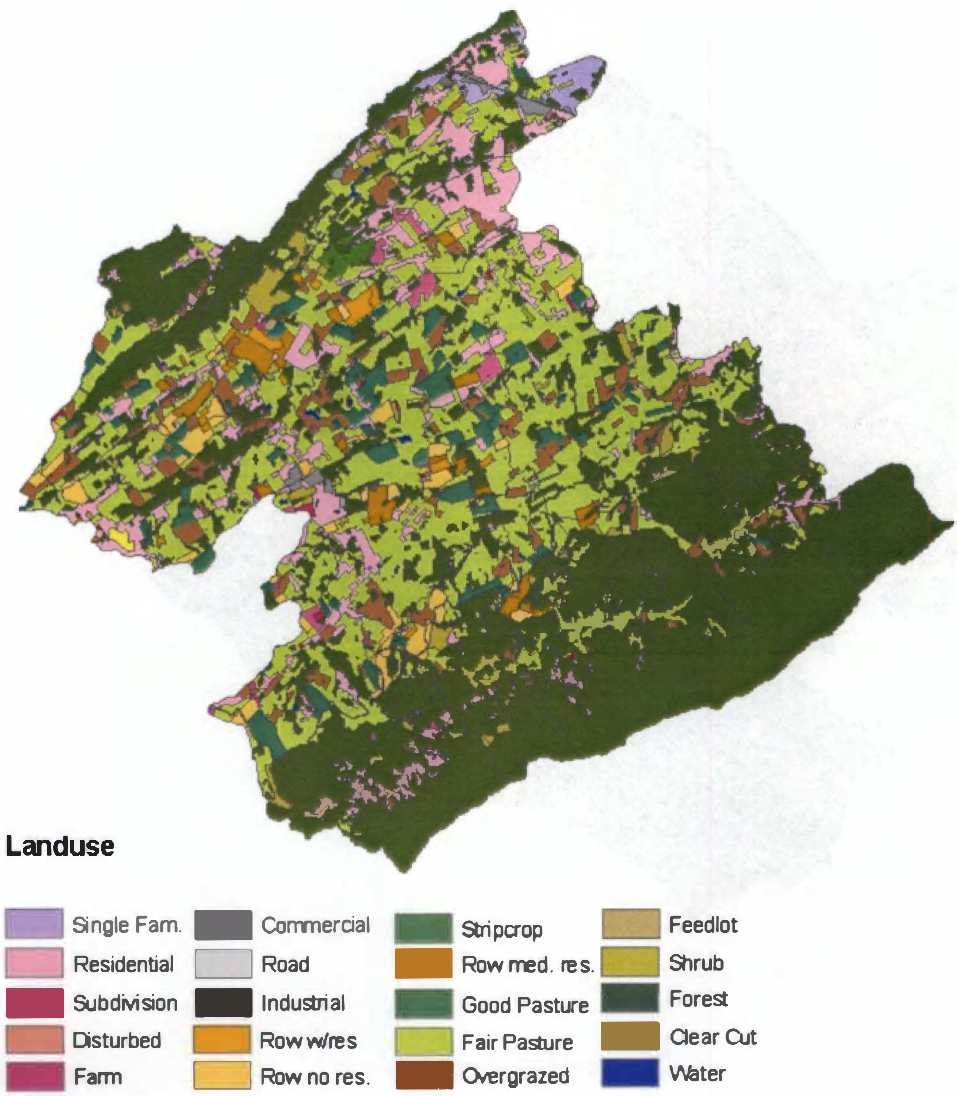


Figure 3. Landuse in the Nails and Ellejoy Creek watersheds.

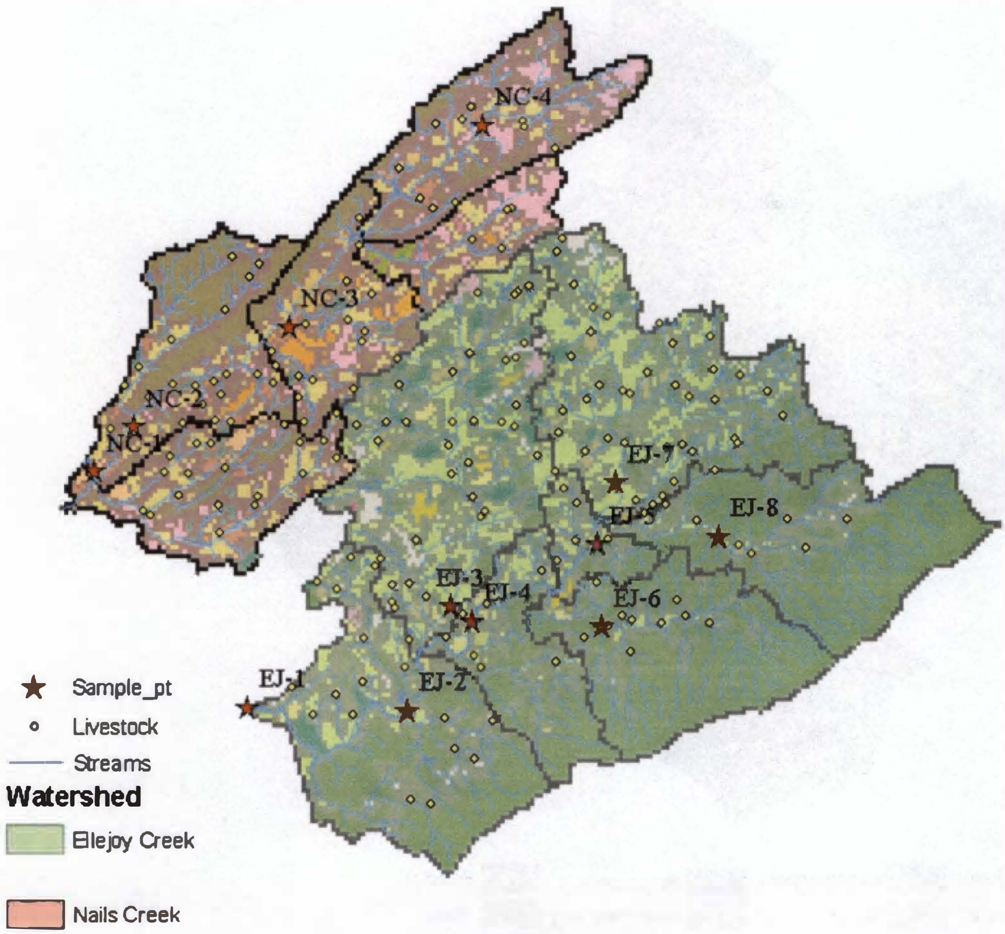


Figure 4. Landuse and watershed delineation in the Nails and Ellejoy Creek watersheds.

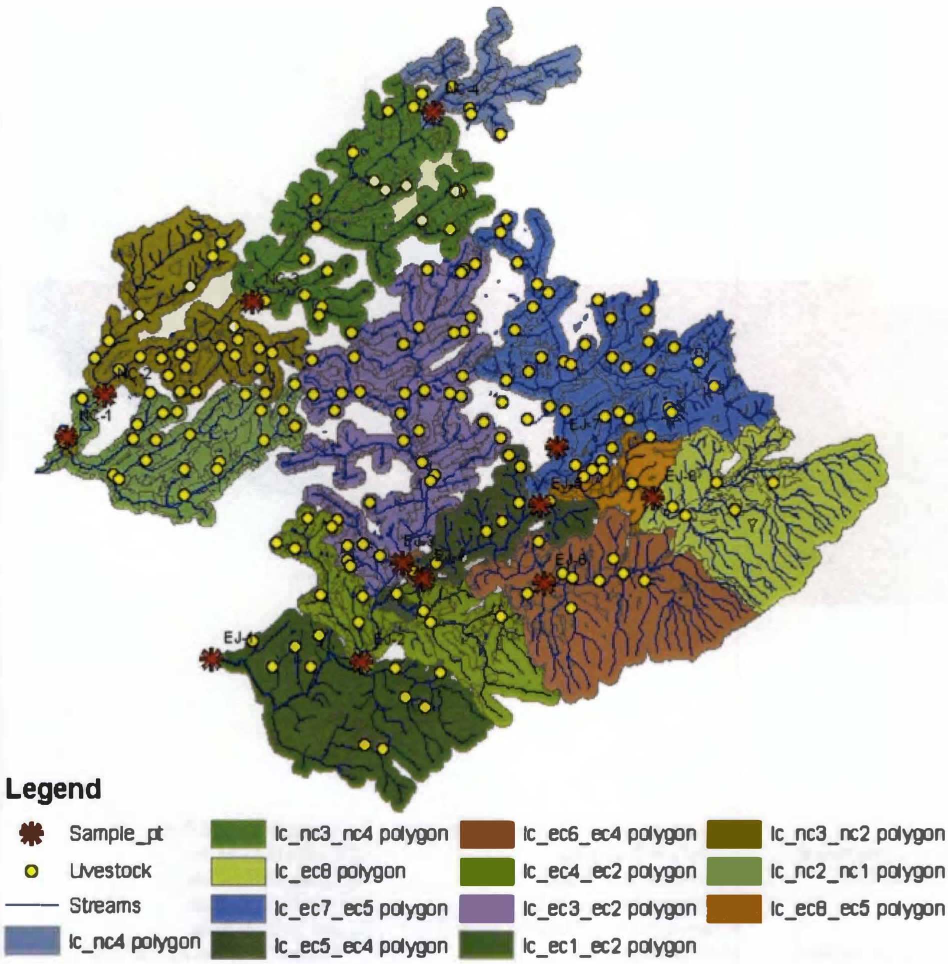
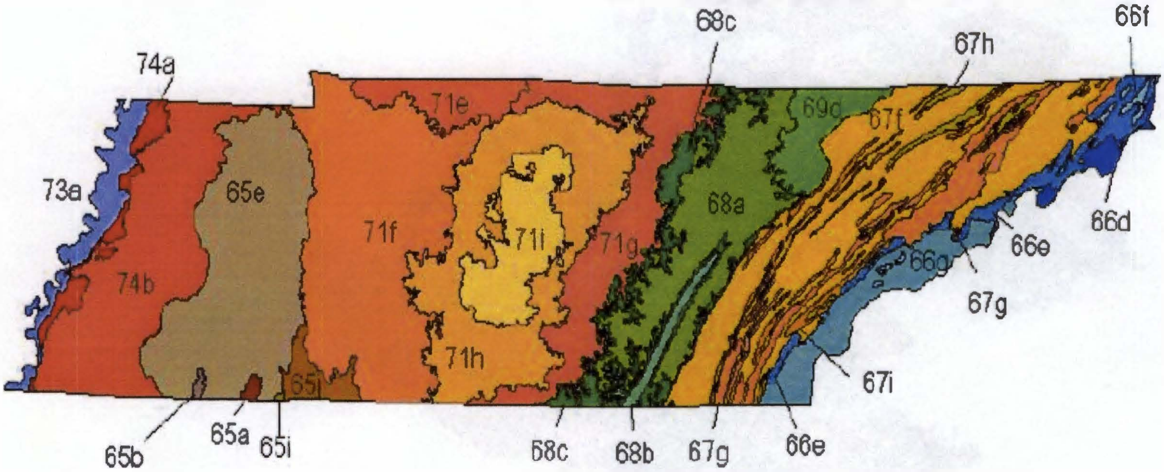


Figure 5. Buffers of contributing areas for each sample site in Nails and Ellejoy Creeks.



65a Blackland Prairie
65b Flatwoods/Alluvial Prairie Margins
65e Southeastern Plains and Hills
65i Fall Line Hills
65j Transition Hills
66d Southern Igneous Ridges and Mtns
66e Southern Sedimentary Ridges
66f Limestone Valleys and Coves
66g Southern Metasedimentary Mountains
67f Southern Limestone/Dolomite Valleys and Low Rolling Hills
67g Southern Shale Valleys
67h Southern Sandstone Ridges
67i Southern Dissected Ridges & Knobs
68a Cumberland Plateau
68b Sequatchie Valley
68c Plateau Escarpment
69d Cumberland Mountains
71e Western Pennyroyal Karst
71f Western Highland Rim
71g Eastern Highland Rim
71h Outer Nashville Basin
71i Inner Nashville Basin
73a Northern Mississippi Alluvial Plain
74a Bluff Hills
74b Loess Plains

Figure 6. Tennessee Level IV ecoregions.
Source: Development of Regionally Based Numeric Interpretations of Tennessee's Narrative Biological Integrity Criterion, 2001.

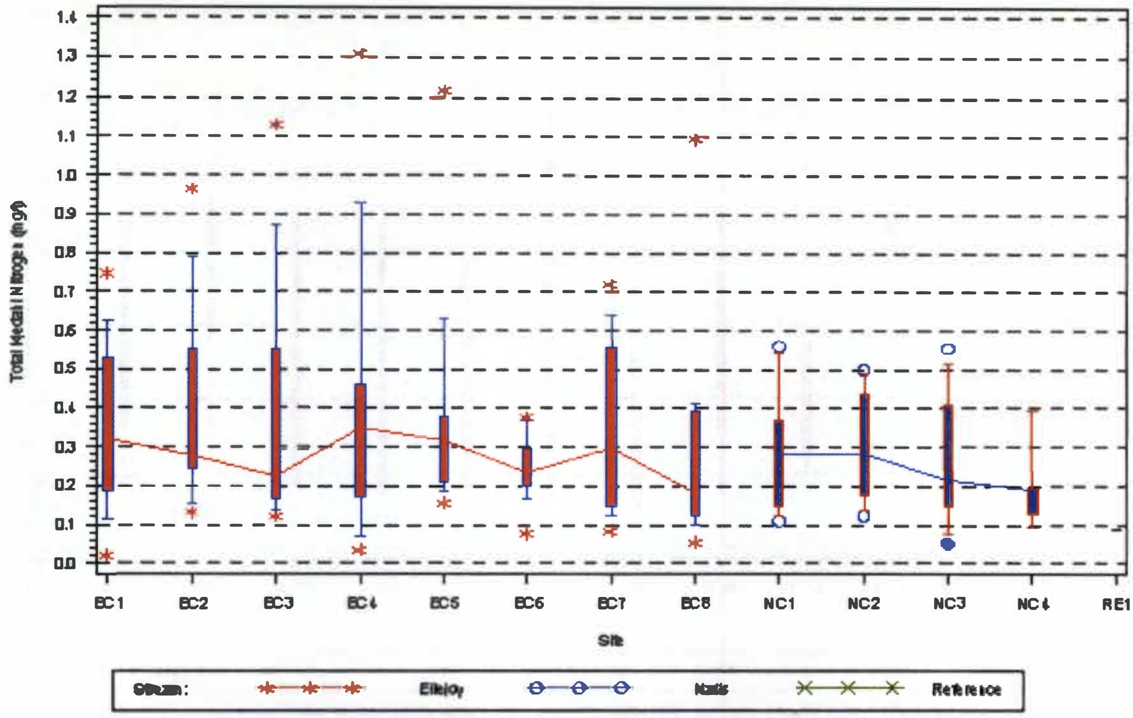


Figure 7. Total Kjedahl Nitrogen (mg/L) for Nails Creek, Ellejoy Creek, and the reference stream data.

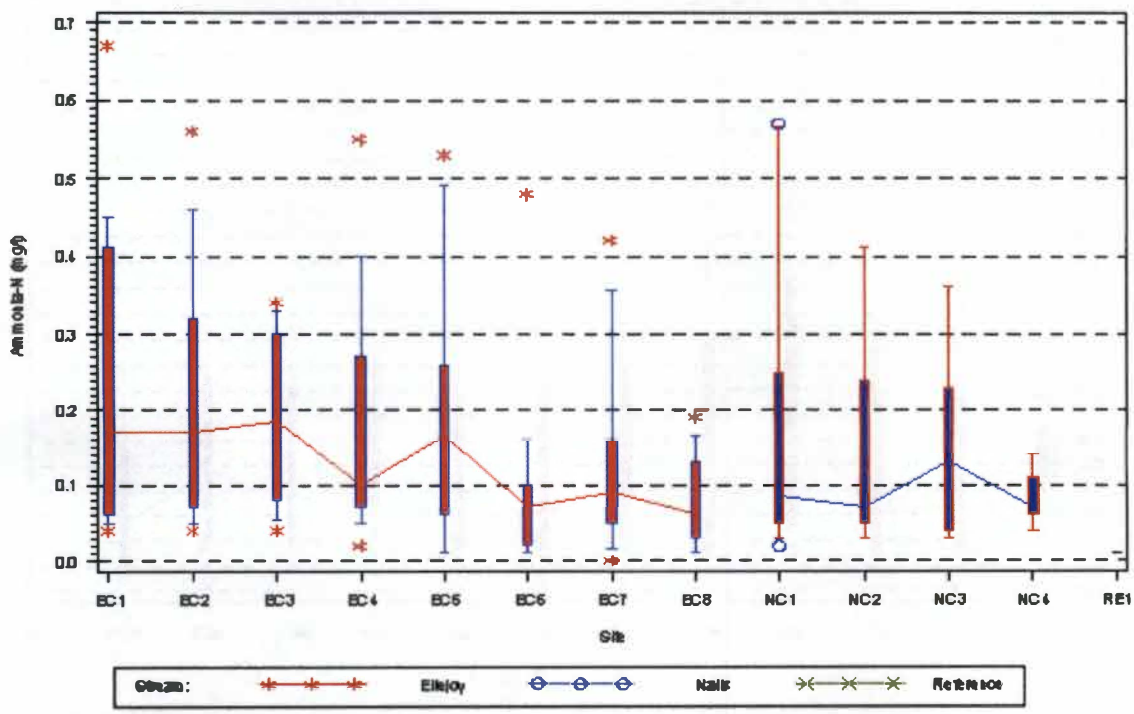


Figure 8. Ammonia-N (mg/L) for Nails Creek, Ellejoy Creek, and the reference stream data.

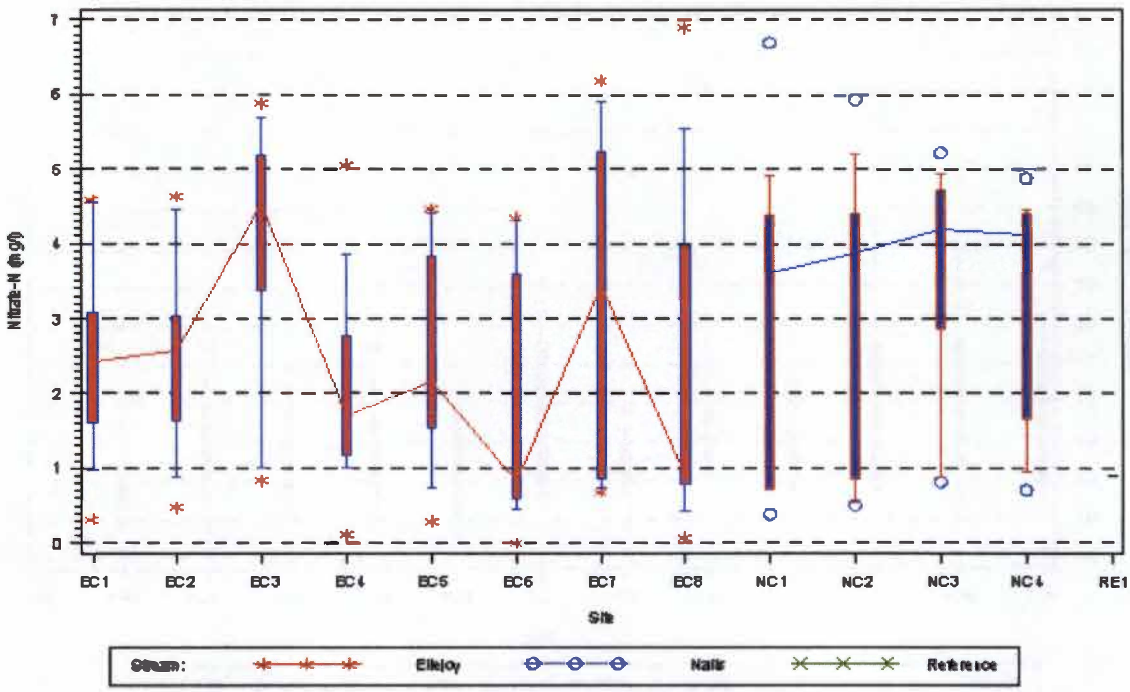


Figure 9. Nitrate-N (mg/L) for Nails Creek, Ellejoy Creek, and the reference stream data.

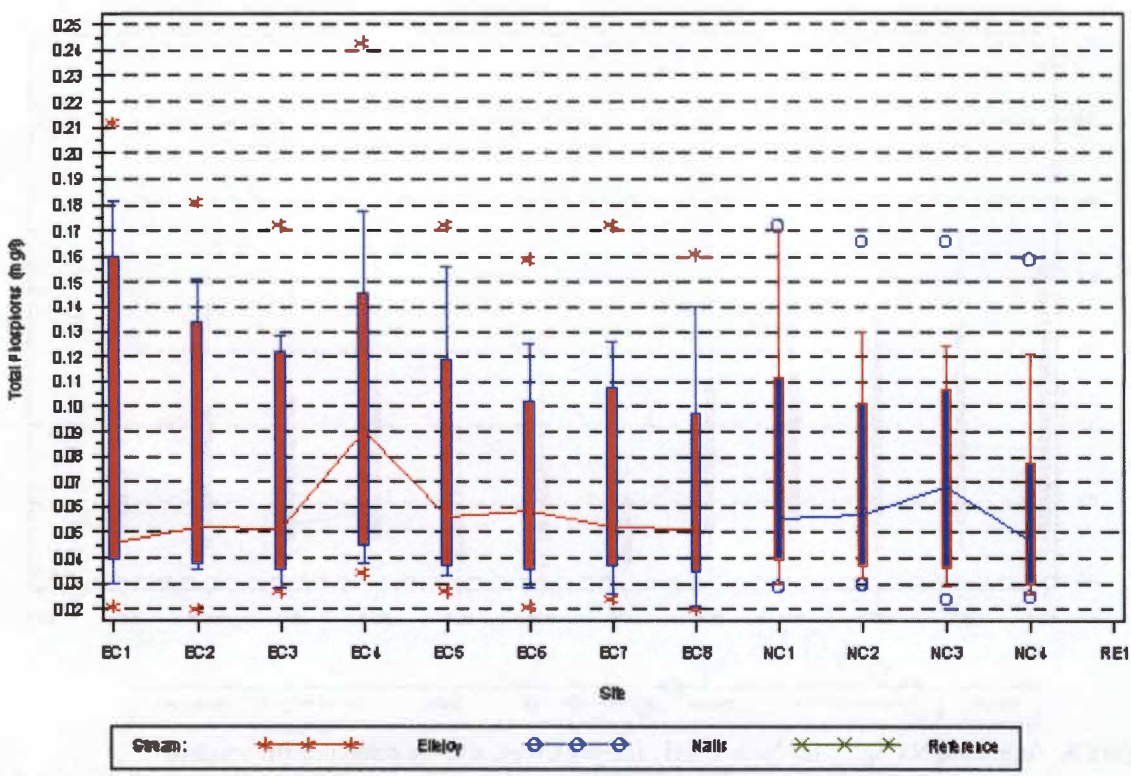


Figure 10. Total Phosphorus (mg/L) for Nails Creek and Ellejoy Creek.

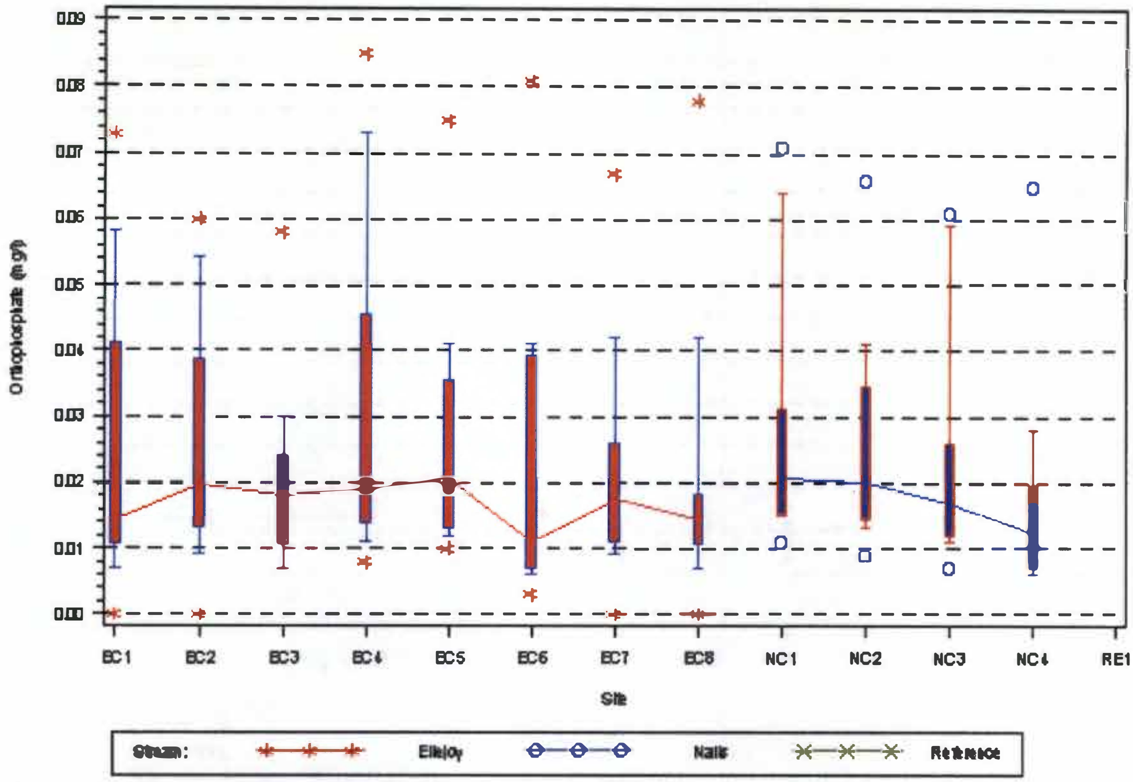


Figure 11. Orthophosphate (mg/L) for Nails Creek and Ellejoy Creek.

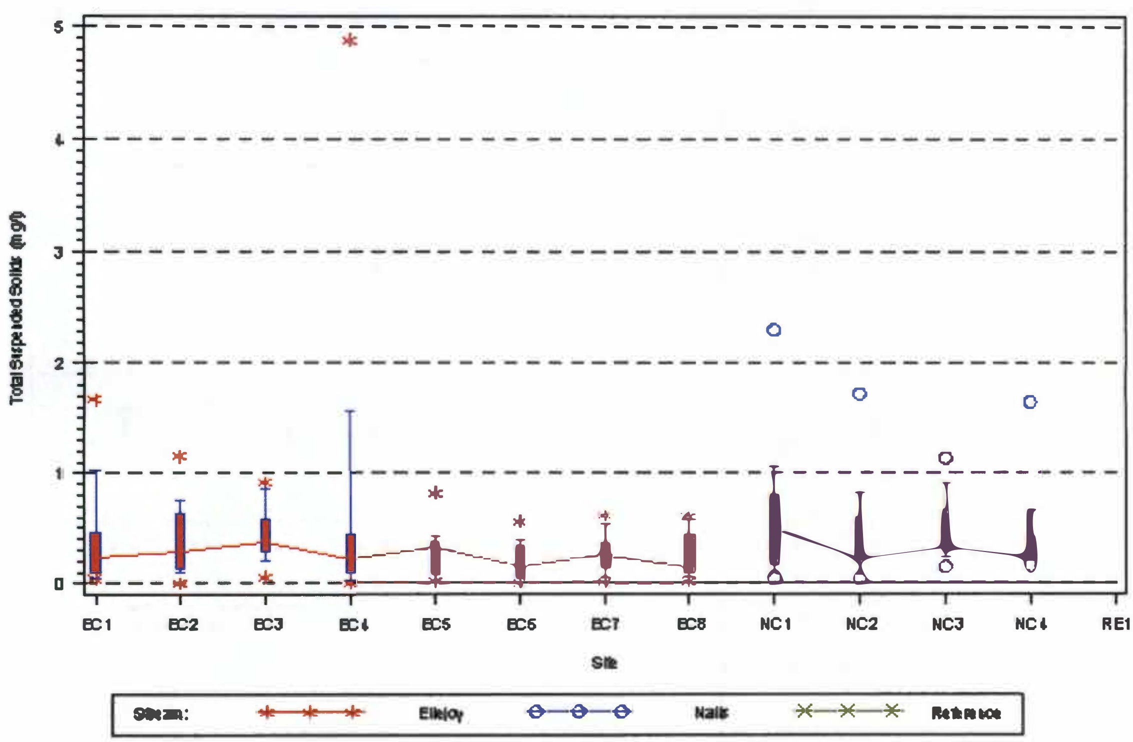


Figure 12. Total Suspended Solids (mg/L) for Nails Creek, Ellejoy Creek and reference stream data.

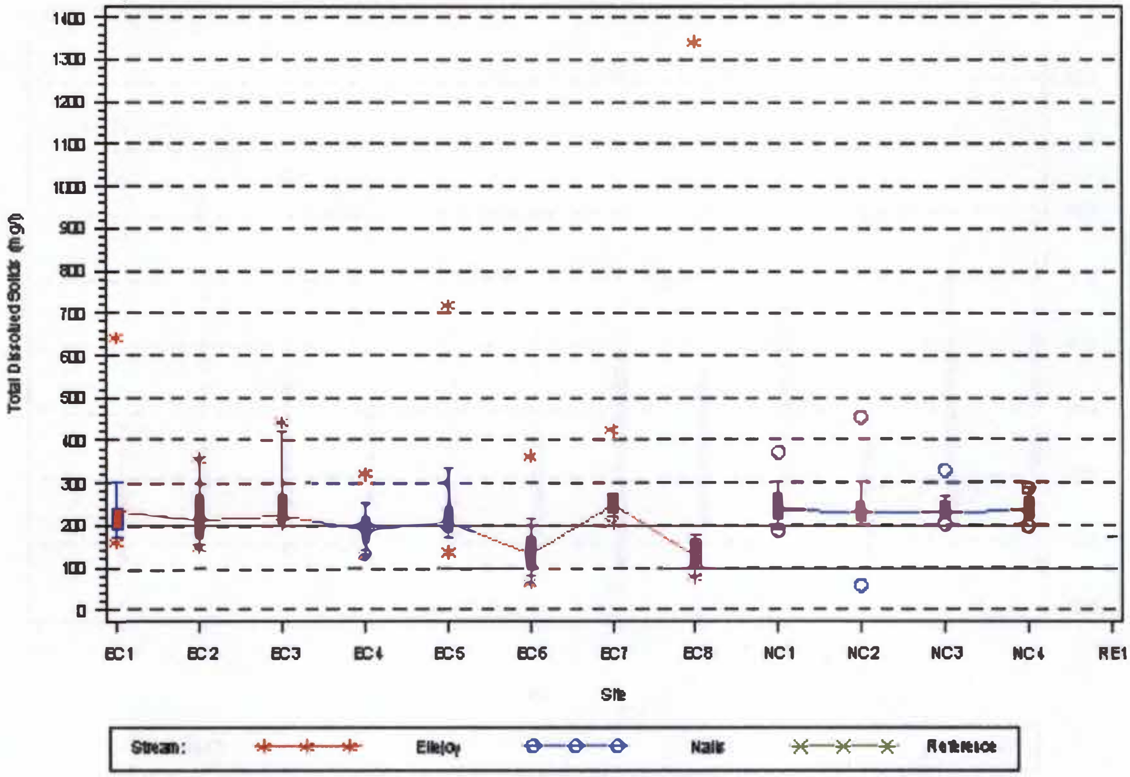


Figure 13. Total Dissolved Solids (mg/L) for Nails Creek, Ellejoy Creek, and reference stream data.

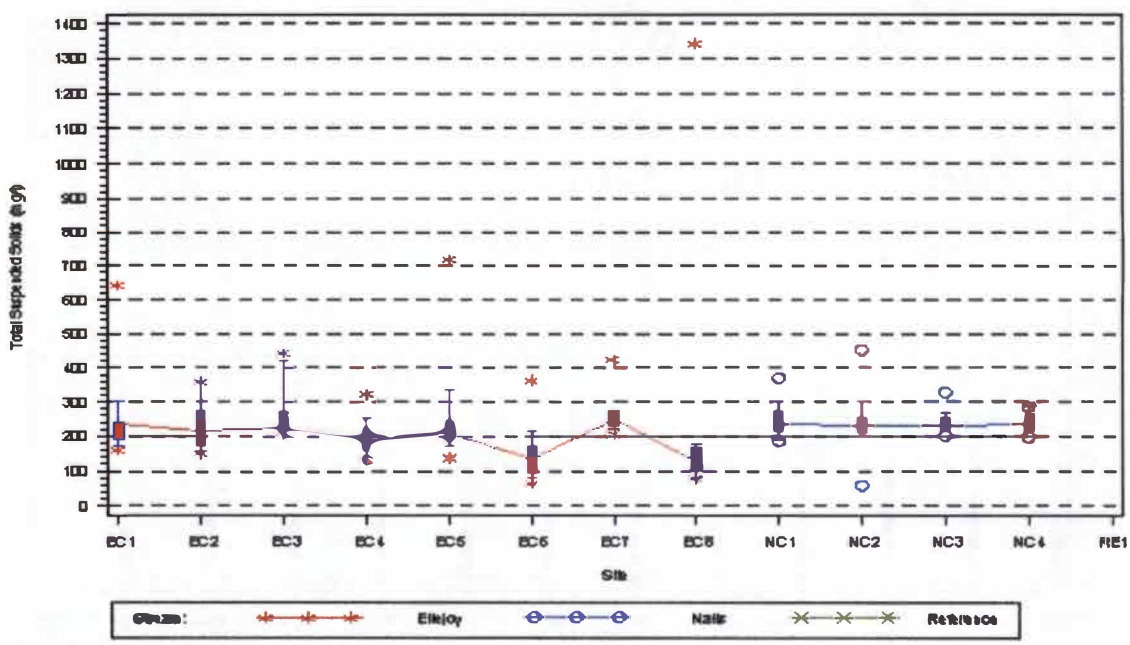


Figure 14. Total Solids (mg/L) for Nails Creek and Ellejoy Creek.

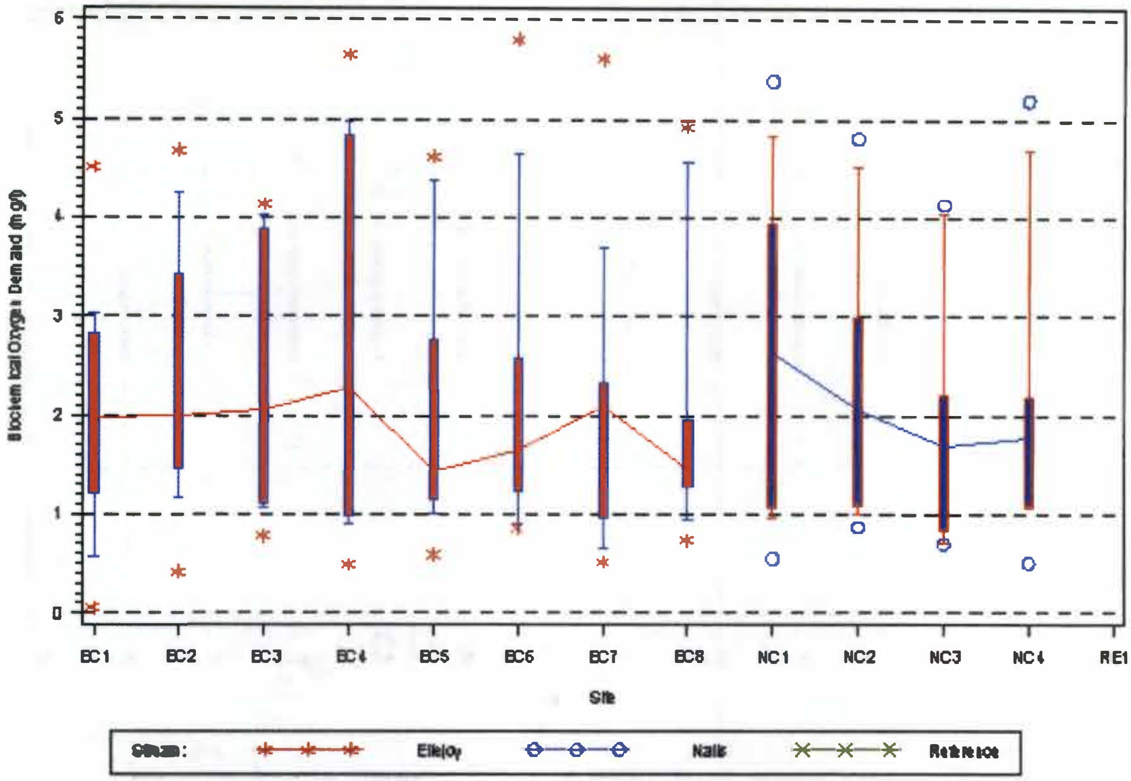


Figure 15. Biochemical Oxygen Demand (mg/L) for Nails Creek and Ellejoy Creek.

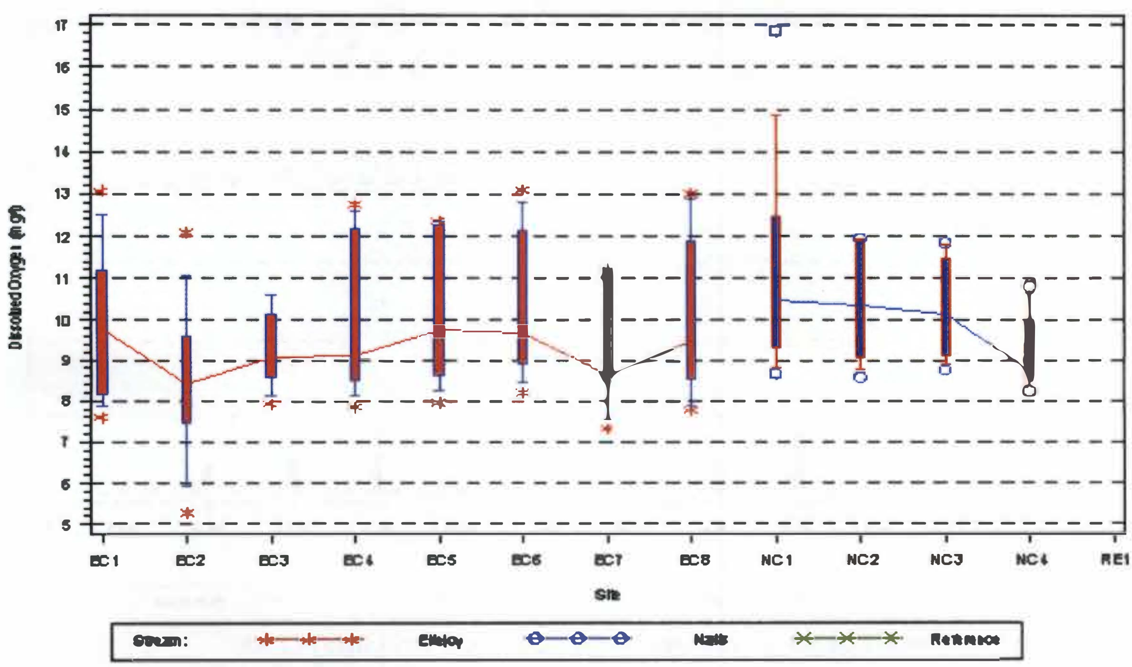


Figure 16. Dissolved Oxygen (mg/L) for Nails Creek and Ellejoy Creek.

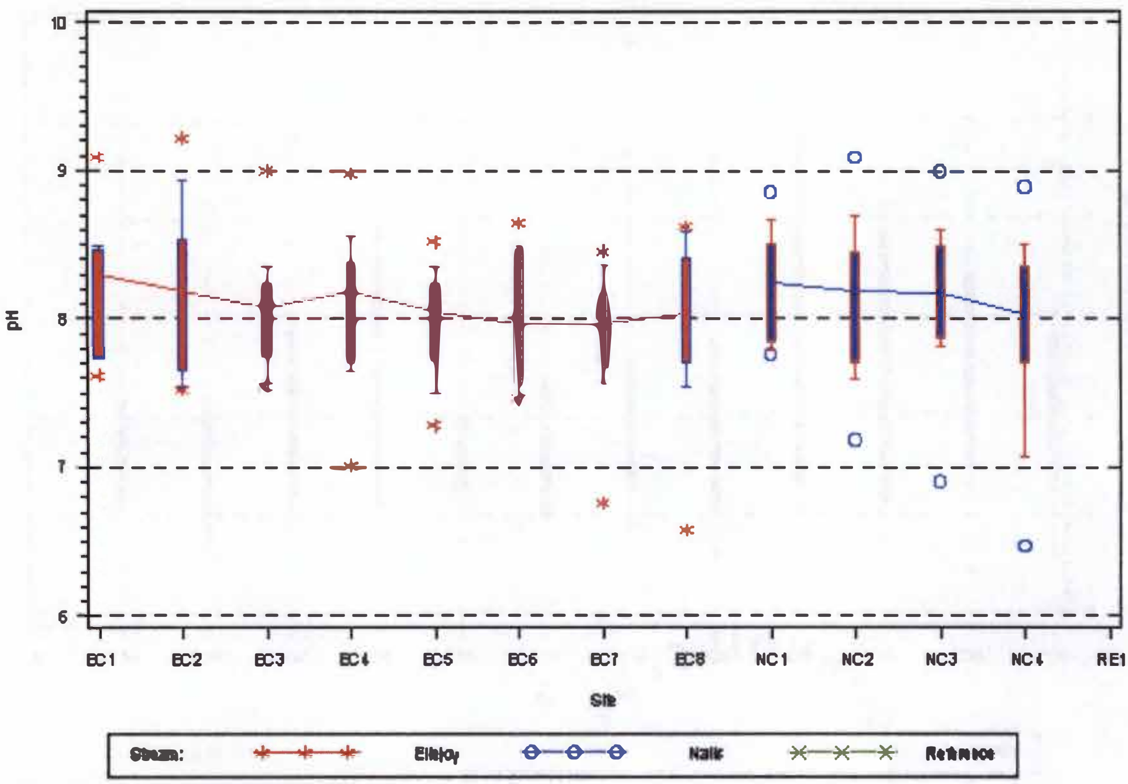


Figure 17. pH for Nails Creek and Ellejoy Creek.

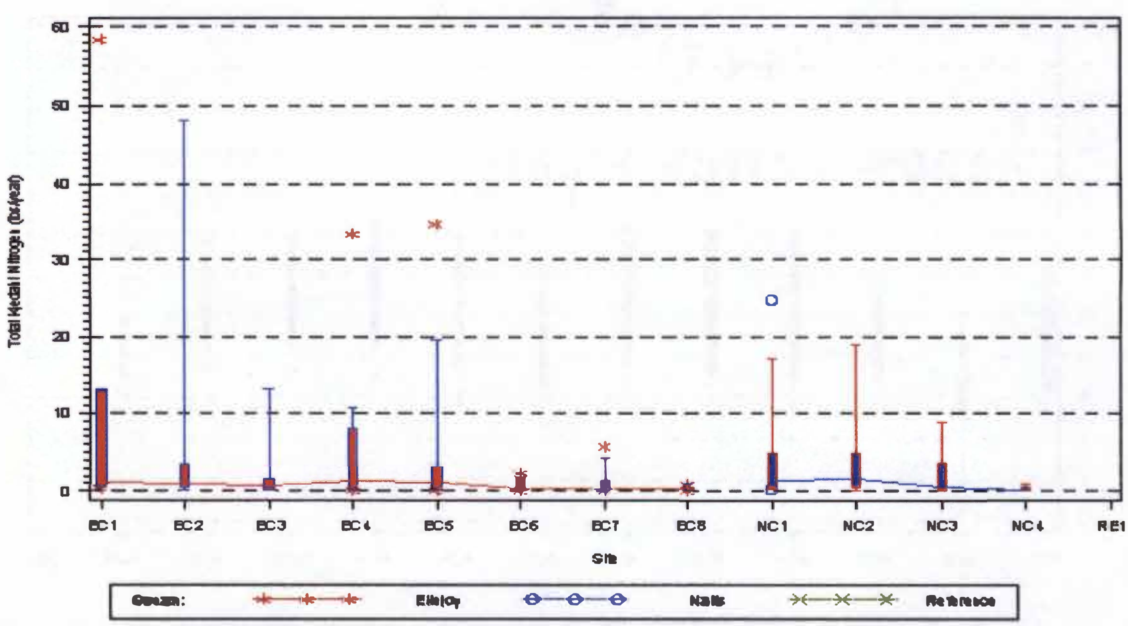


Figure 18. Total Kjedahl Nitrogen (metric tons/yr) for Nails Creek and Ellejoy Creek.

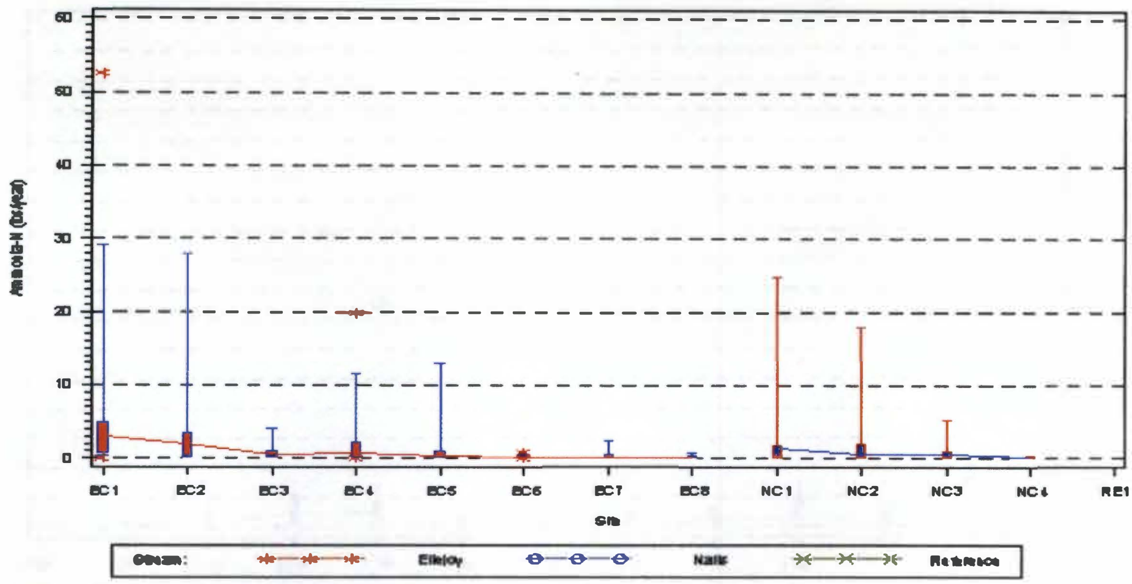


Figure 19. Ammonia-N (metric tons/yr) for Nails Creek and Ellejoy Creek.

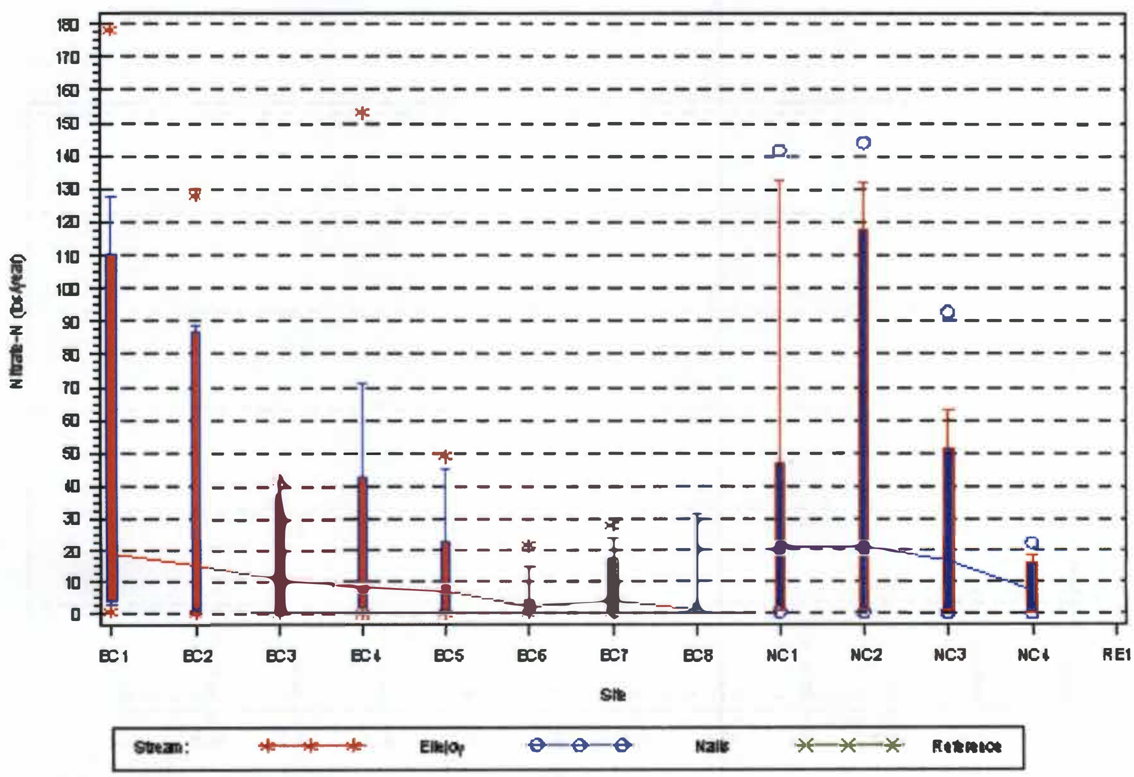


Figure 20. Nitrate-N (metric tons/yr) for Nails Creek and Ellejoy Creek.

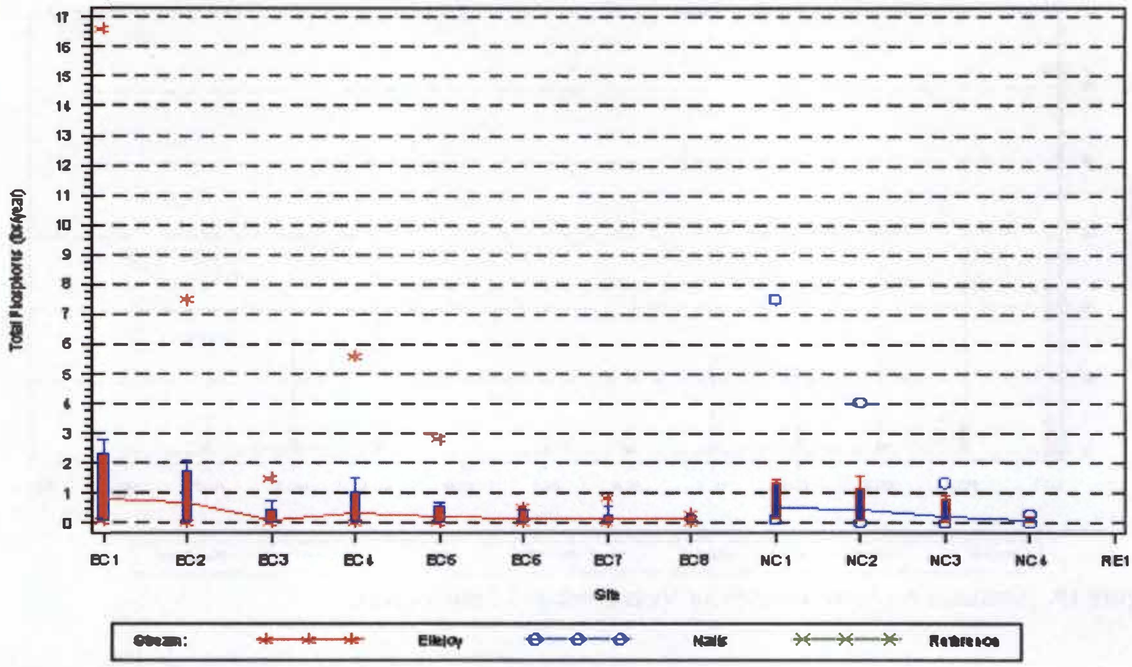


Figure 21. Total Phosphate (metric tons/yr) for Nails Creek and Ellejoy Creek.

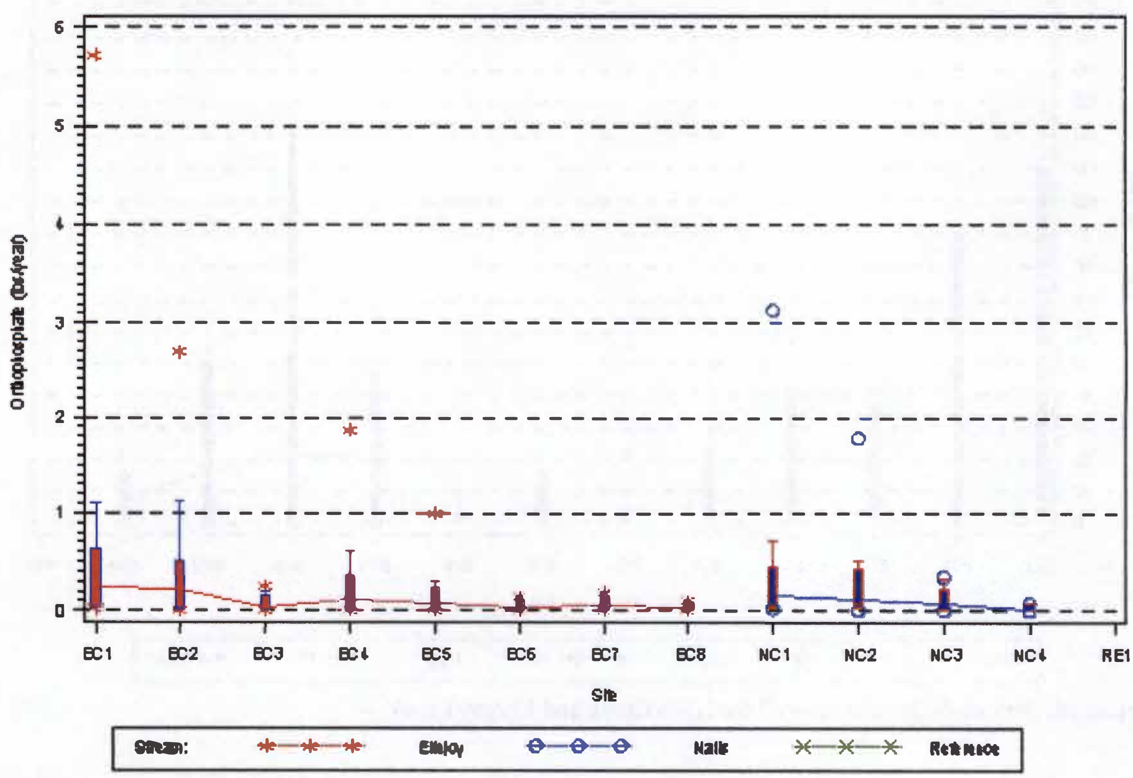


Figure 22. Orthophosphate (metric tons/yr) for Nails Creek and Ellejoy Creek.

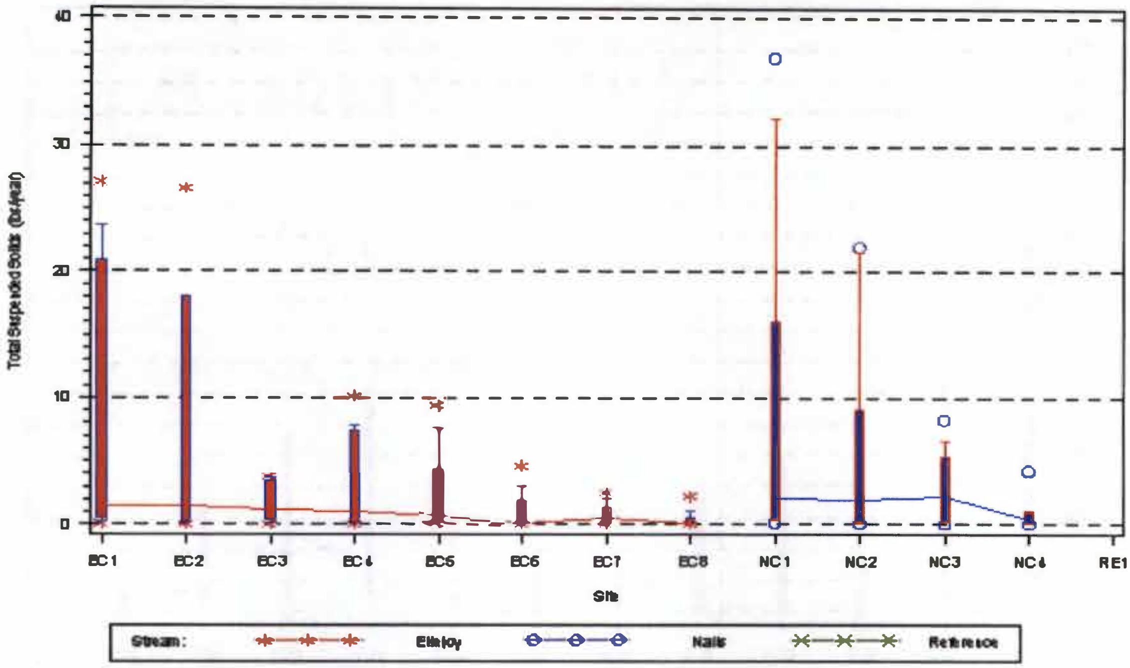


Figure 23. Total Suspended Solids (metric tons/yr) for Nails Creek and Ellejoy Creek.

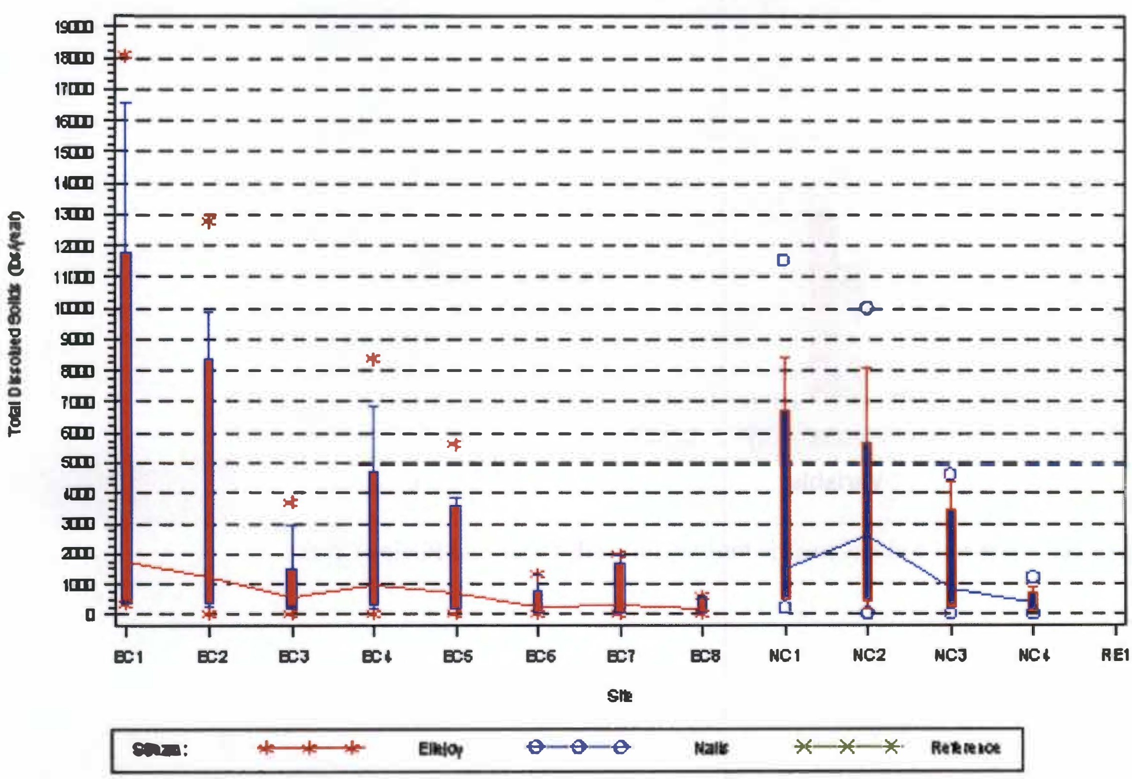


Figure 24. Total Dissolved Solids (metric tons/yr) for Nails Creek and Ellejoy Creek.

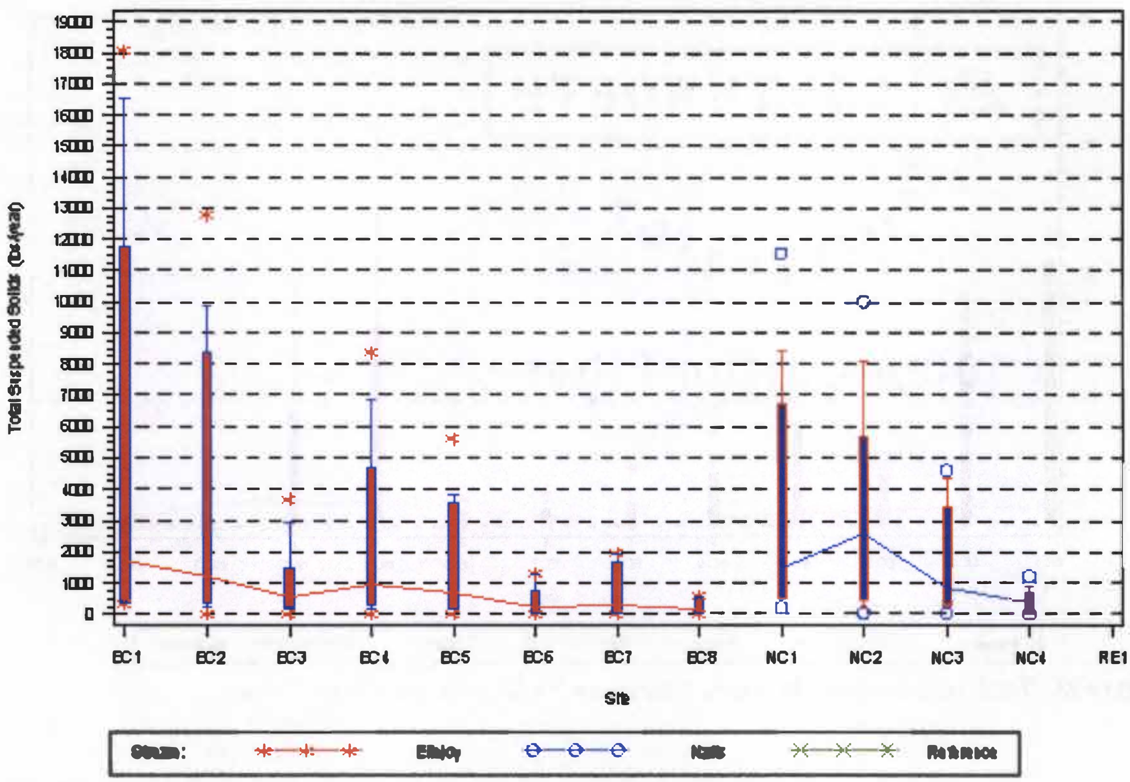


Figure 25. Total Solids (metric tons/yr) for Nails Creek and Ellejoy Creek.

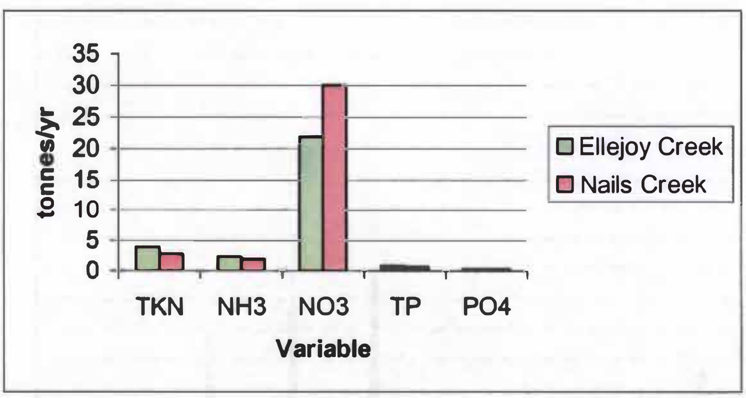


Figure 26. Nutrient Loadings (metric tons/yr) for Nails Creek and Ellejoy Creek.

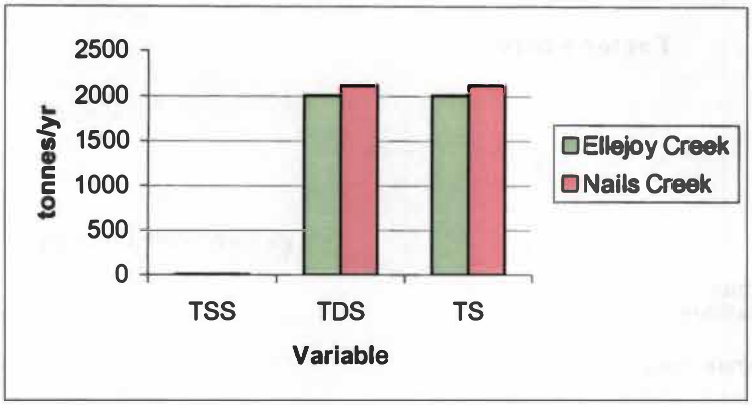


Figure 27. Sediment Loadings (metric tons/yr) for Nails Creek and Ellejoy Creek.

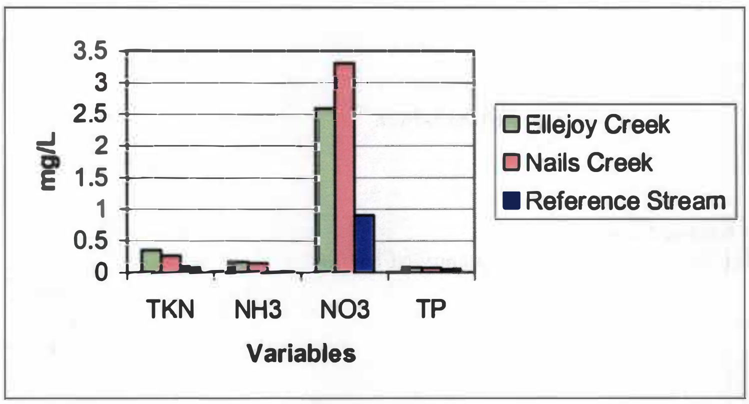


Figure 28. Nutrients for Nails, Ellejoy, and the reference stream.

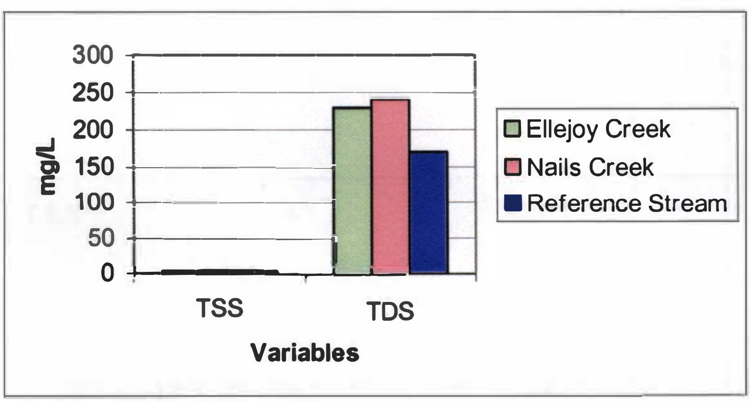


Figure 29. Sediments for Nails, Ellejoy, and the reference stream.

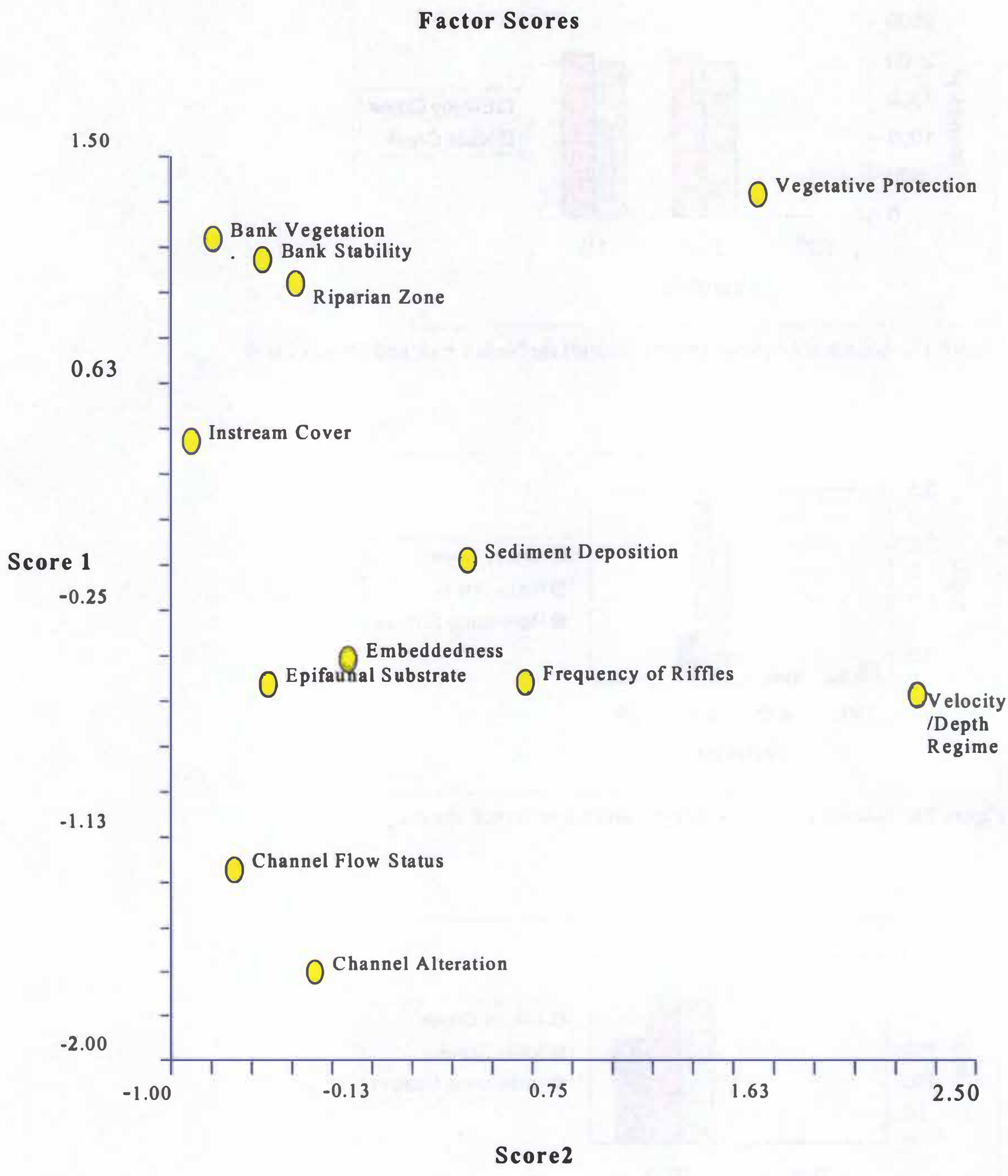


Figure 30. Principal Component Analysis of environmental variables across all sites and samples, Axis 1.

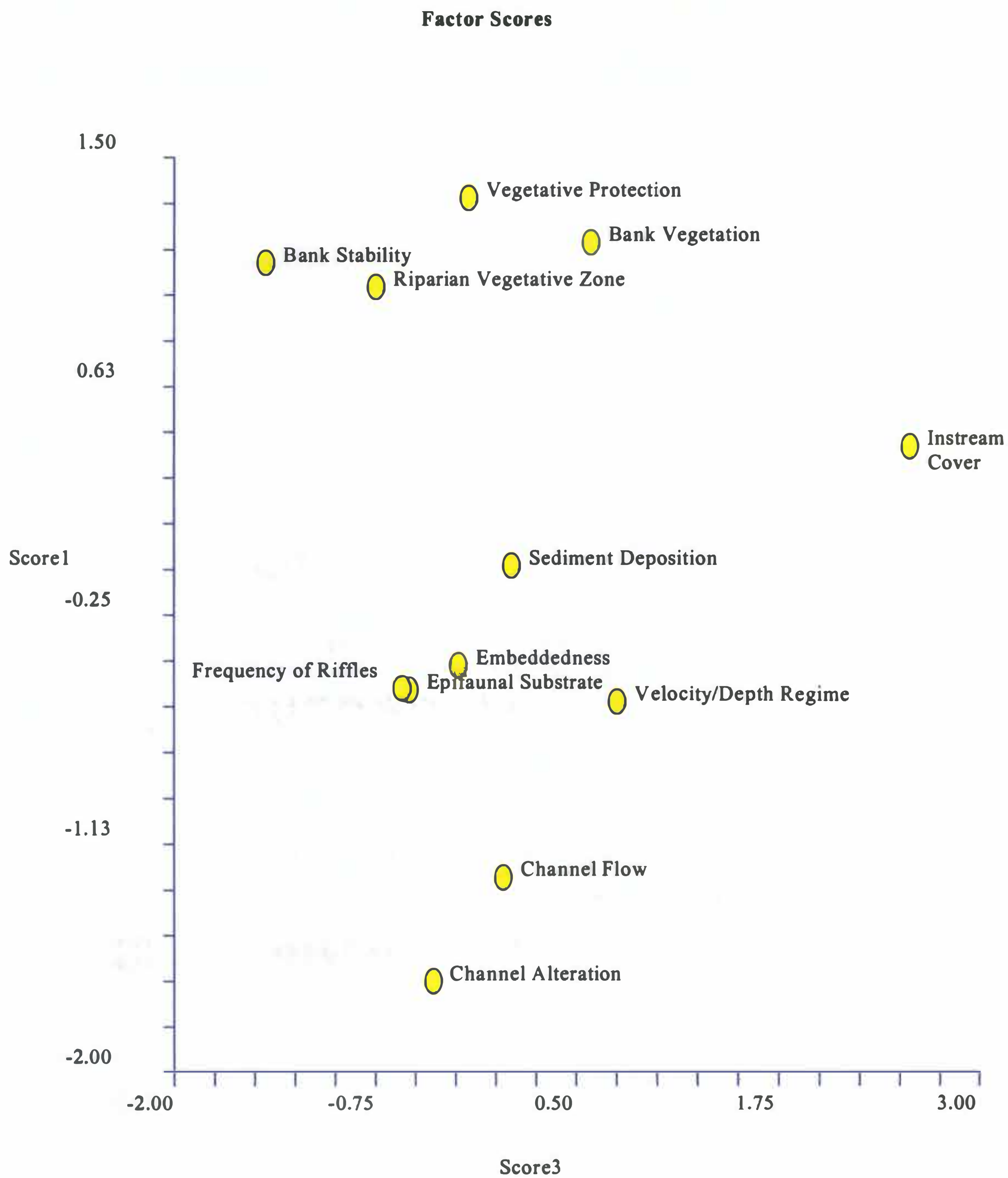


Figure 31. Principal Component Analysis of environmental variables across all sites and samples, Axis 2.

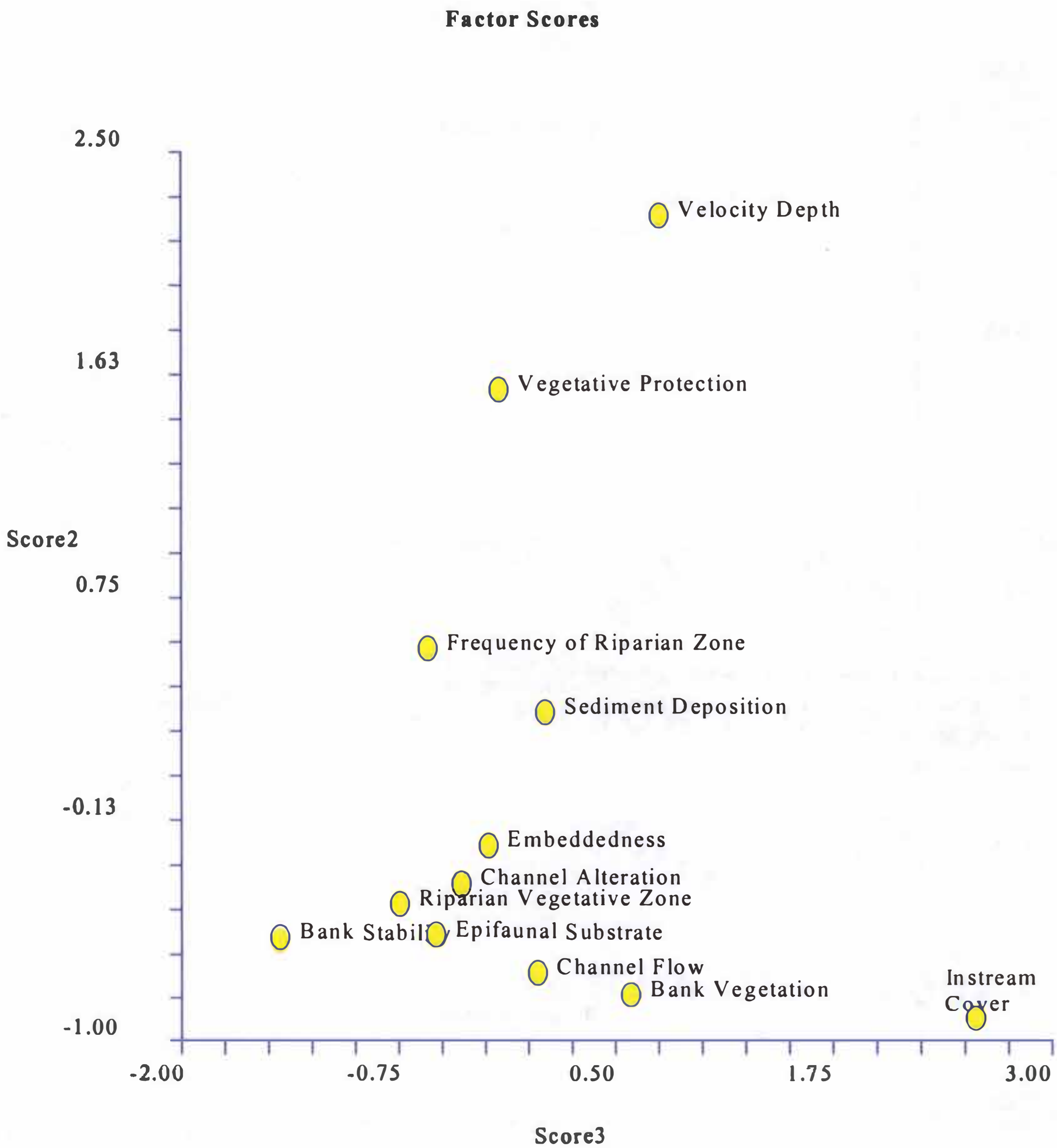


Figure 32. Principle Component Analysis of environmental variables across all sites and samples, Axis 3.

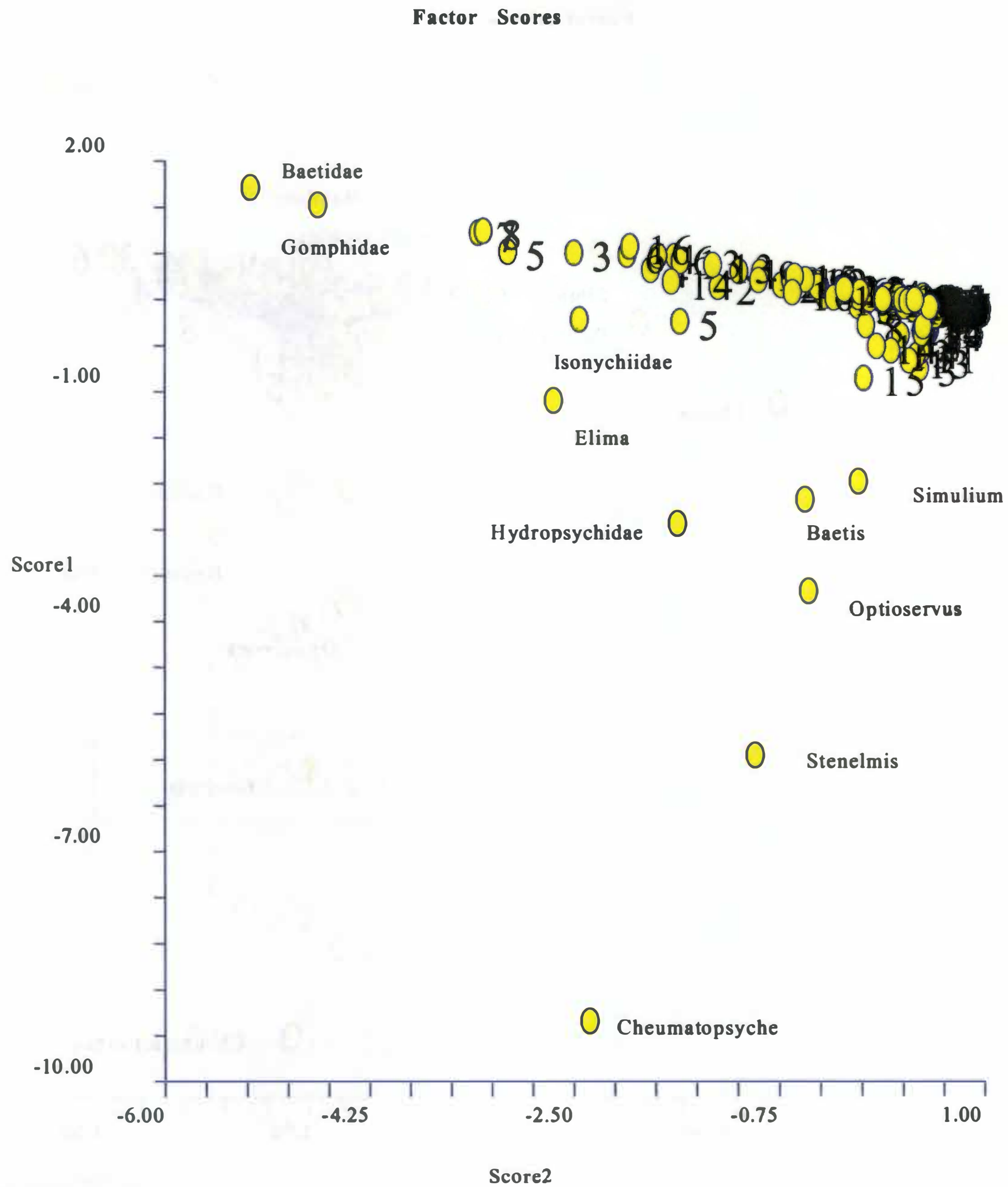


Figure 33. Principle Component Analysis of species across all sites and sampling dates, Axis 1.

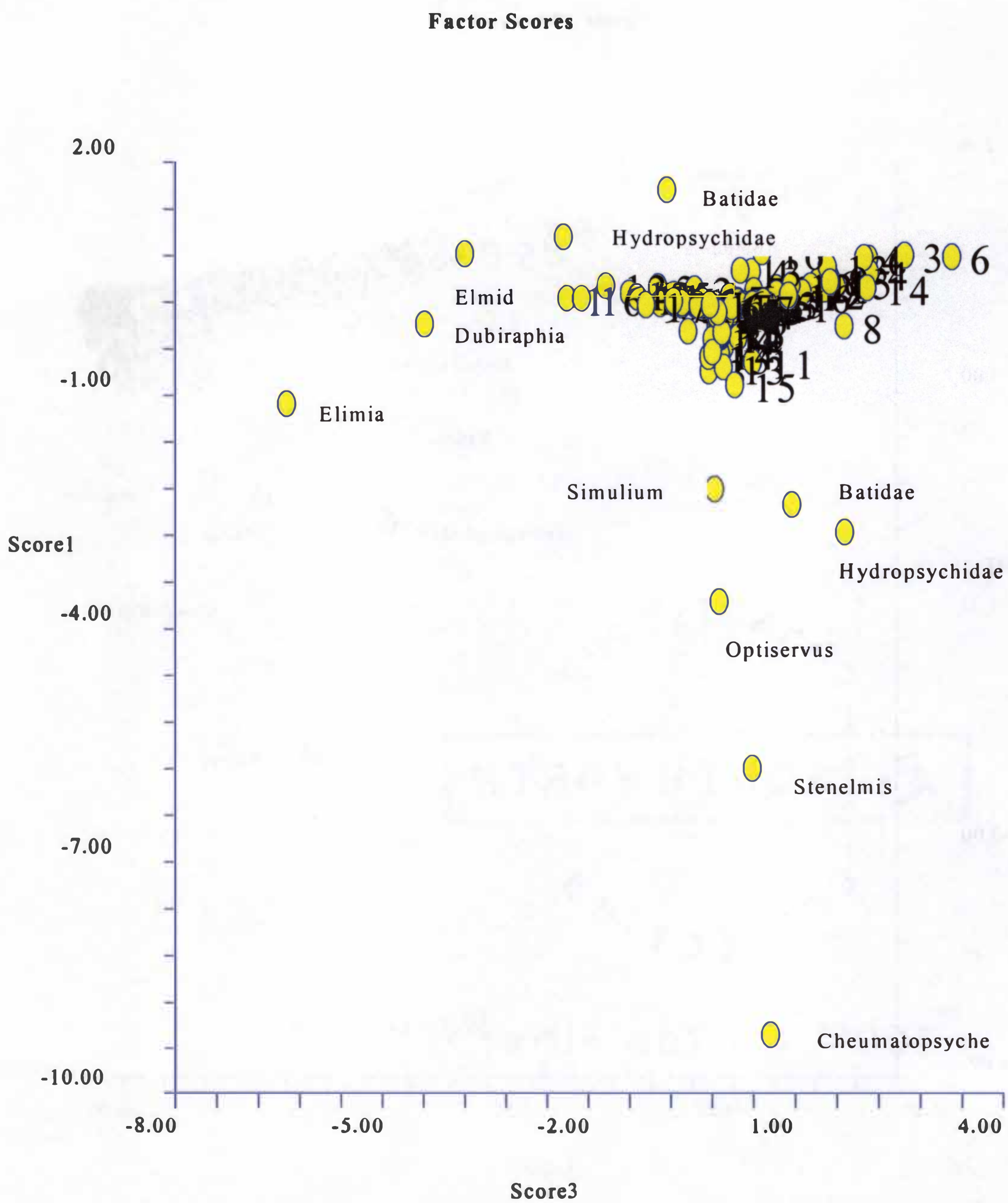


Figure 34. Principle Component Analysis of species across all sites and sampling dates, Axis 2.

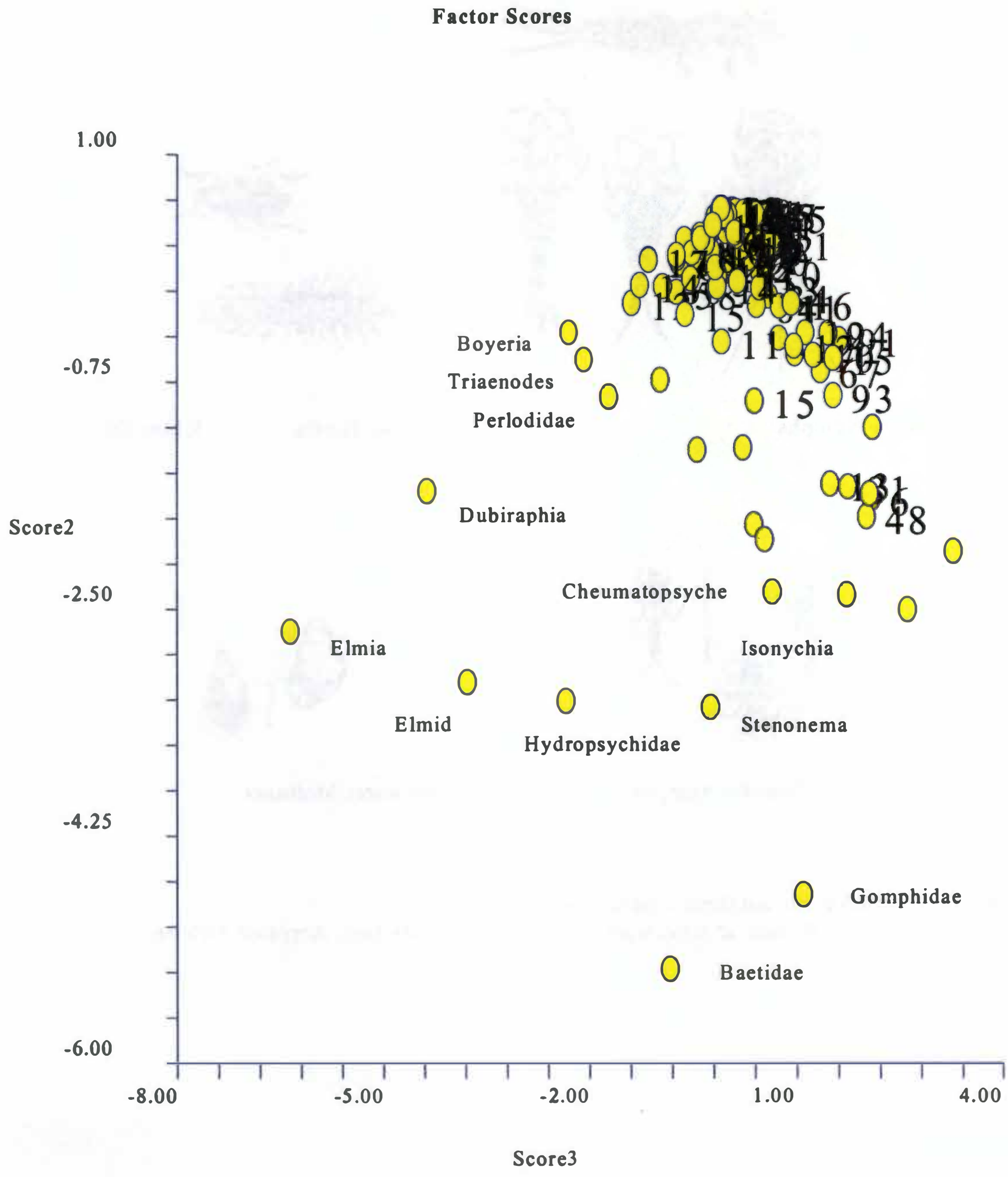


Figure 35. Principle Component Analysis of species across all sites and sampling dates, Axis 3.

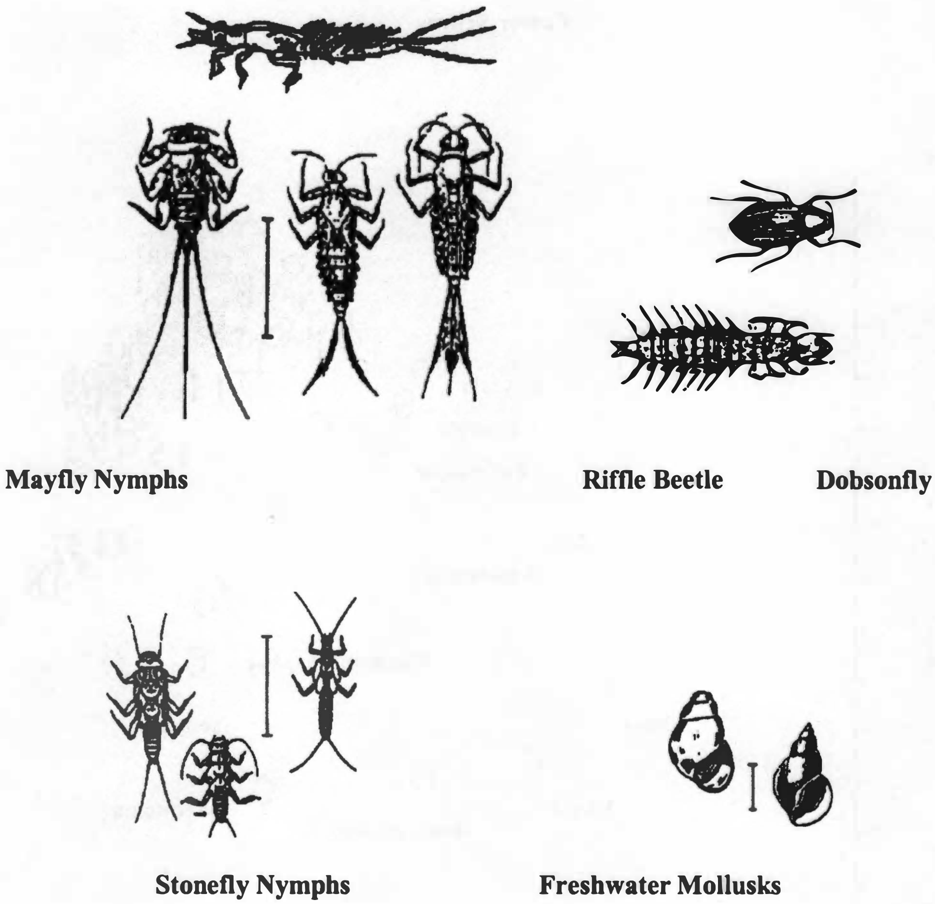


Figure 36. Pollution Intolerant Benthic Macroinvertebrates.
Source: Water Studies Website at http://www.educ.sfu.ca/nbcr/cat1.html, Accessed 3/20/04.

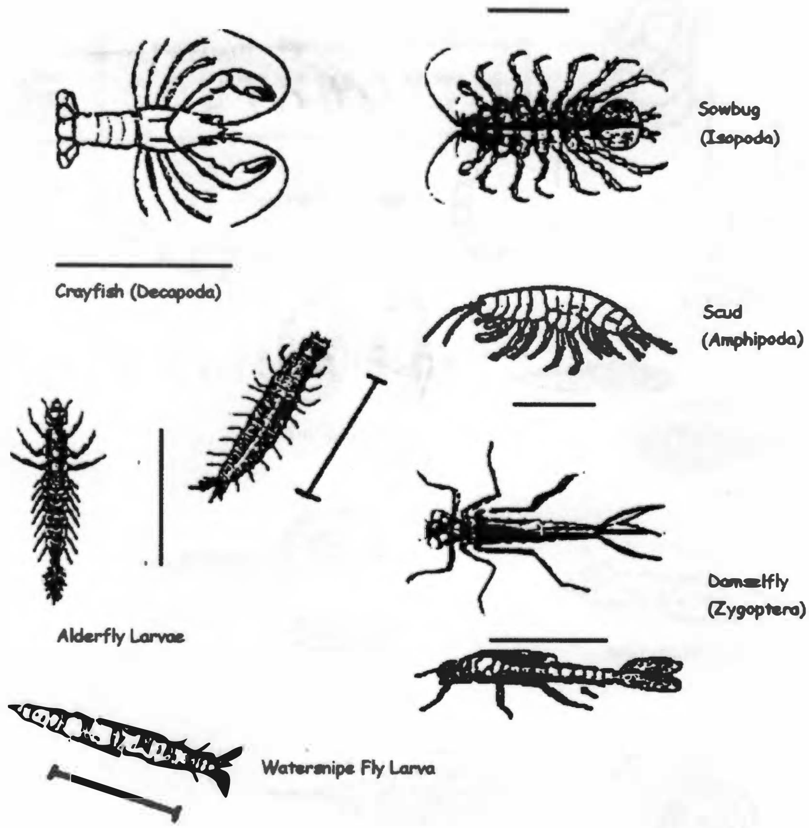


Figure 37. Somewhat Pollution Tolerant Benthic Macroinvertebrates.
Source: Water Studies Website at http://www.educ.sfu.ca/nbcr/cat1.html, Accessed 3/20/04.

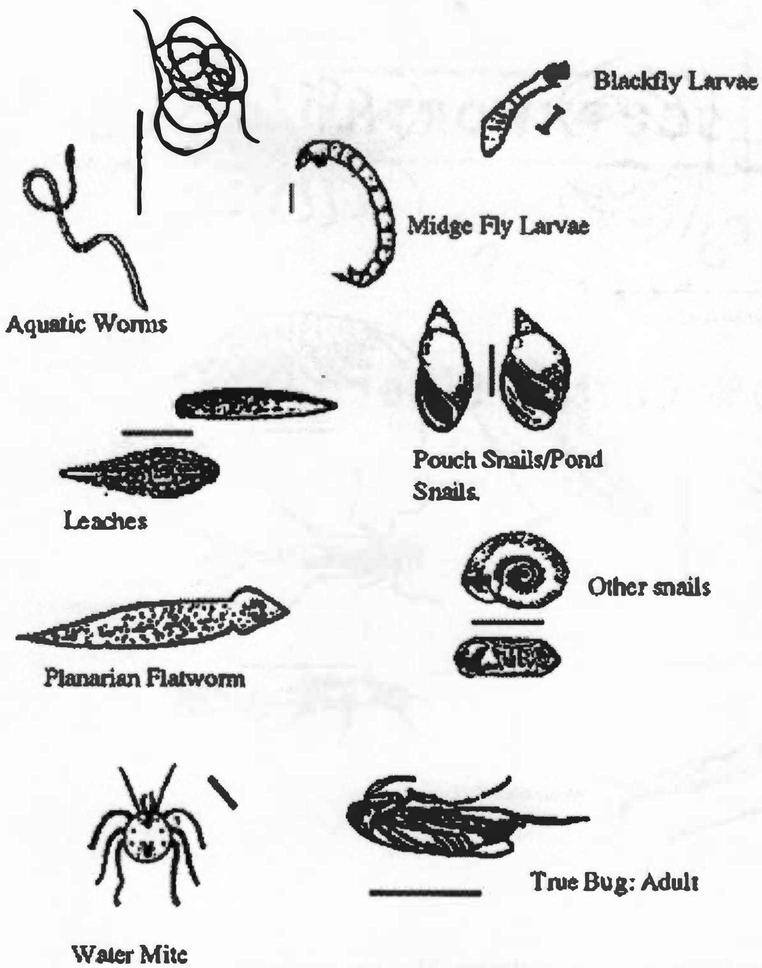


Figure 38. Pollution Tolerant Benthic Macroinvertebrates.
Source: Water Studies Website at http://www.educ.sfu.ca/nbcr/cat1.html, Accessed 3/20/04.

APPENDIX C. SUPPLEMENTAL INFORMATION

Ellejoy Creek Total Solids Mean Separation

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TS Mean
Model	7	133451.65	19064.52	0.80	0.5883	0.05	67.31	154.23	229.13
Error	88	2093404.56	23788.68						
Corrected Total	95	2226856.21							

Ellejoy Creek Total Solids Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	7	133451.65	19064.52	0.80	0.58

Ellejoy Creek Total Suspended Solids Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TSS Mean
Model	7	2.15	0.30	0.99	0.44	0.07	153.67	0.55	0.36
Error	88	27.45	0.31						
Corrected Total	95	29.60							

Ellejoy Creek Total Suspended Solids Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	7	2.15327183	0.30761026	0.99	0.4467

Ellejoy Creek Total Dissolved Solids Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TDS Mean
Model	7	133450.52	19064.36	0.80	0.58	0.05	67.31	154.23	229.12
Error	88	2093386.06	23788.47						
Corrected Total	95	2226836.58							

Ellejoy Creek Total Dissolved Solids Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	7	133450.52	19064.36	0.80	0.58

Ellejoy Creek Total Phosphorus Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TP Mean
Model	7	0.01	0.01	0.58	0.77	0.04	68.87	0.05	0.08
Error	88	0.26	0.03						
Corrected Total	95	0.27							

Ellejoy Creek Total Phosphorus Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	7	0.01	0.01	0.58	0.77

Ellejoy Creek Total Orthophosphate Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	PO4 Mean
Model	7	0.01	0.01	0.41	0.89	0.03	85.86	0.02	0.024
Error	87	0.03	0.04						
Corrected Total	94	0.03							

Ellejoy Creek Total Orthophosphate Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	7	0.01	0.01	0.41	0.89

Ellejoy Creek Total Kjedahl Nitrogen Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TKN Mean
Model	7	0.26	0.03	0.52	0.81	0.04	76.13	0.26	0.35
Error	81	5.81	0.07						
Corrected Total	88	6.07							

Ellejoy Creek Total Kjedahl Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	7	0.26193082	0.03741869	0.52	0.8159

Ellejoy Creek Ammonia-N Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	NH3 Mean
Model	7	0.23	0.03	1.50	0.18	0.12	90.19	0.15	0.16
Error	75	1.70	0.02						
Corrected Total	82	1.94							

Ellejoy Creek Ammonia-N Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	7	0.23	0.03	1.50	0.18

Nails Creek Total Solids Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TS Mean
Model	3	728.35	242.78	0.08	0.97	0.05	23.36	56.16	240.42
Error	44	138817.37	3154.94						
Corrected Total	47	139545.73							

Nails Creek Total Solids Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	3	728.35	242.78	0.08	0.97

Nails Creek Total Dissolved Solids Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TDS Mean
Model	3	727.67	242.55	0.08	0.97	0.01	23.36	56.16	240.41
Error	44	138807.69	3154.72						
Corrected Total	47	139535.36							

Nails Creek Total Dissolved Solids Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	3	727.67	242.55	0.08	0.97

Nails Creek Total Suspended Solids Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TSS Mean
Model	3	0.31	0.10	0.47	0.70	0.03	98.76	0.47	0.47
Error	44	9.79	0.22						
Corrected Total	47	10.11							

Nails Creek Total Suspended Solids Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	3	0.31493733	0.10497911	0.47	0.7038

Nails Creek Total Phosphorus Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TP Mean
Model	3	0.02	0.06	0.32	0.81	0.02	63.69	0.04	0.07
Error	44	0.09	0.02						
Corrected Total	47	0.09							

Nails Creek Total Phosphorus Solids Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	3	0.02	0.06	0.32	0.81

Nails Creek Orthophosphate Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	PO4 Mean
Model	3	0.07	0.02	0.82	0.48	0.05	75.23	0.01	0.02
Error	44	0.01	0.03						
Corrected Total	47	0.01							

Nails Creek Orthophosphate Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	3	0.01	0.02	0.82	0.48

Nails Creek Total Kjedahl Nitrogen Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	TKN Mean
Model	3	0.09	0.03	1.47	0.23	0.10	53.75	0.14	0.26
Error	36	0.73	0.02						
Corrected Total	39	0.82							

Nails Creek Orthophosphate Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	3	0.09	0.03	1.47	0.23

Nails Creek Nitrate-N Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	NO3 Mean
Model	3	2.36	0.78	0.25	0.86	0.01	53.68	1.77	3.30
Error	42	132.27	3.14						
Corrected Total	45	134.64							

Nails Creek Nitrate-N Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	3	2.36257731	0.78752577	0.25	0.8608

Nails Creek Ammonia-N Mean Separation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square	Coeff Var	Root MSE	NH3 Mean
Model	3	0.05	0.01	0.91	0.44	0.07	100.22	0.14	0.14
Error	33	0.69	0.02						
Corrected Total	36	0.74							

Nails Creek Ammonia-N Type 3 Error Rate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	3	0.05	0.01	0.91	0.44

Monthly Flow Data for 2003-2004 in the Nails and Ellejoy Creek Watersheds												
Stream	Site	July	Aug	Aug	Oct	Oct	Nov	Dec	Jan	Jan	Feb	Feb
Ellejoy	1	0.04	0.93	0.19	0.04	0.11	0.03	0.10	0.24	0.16	0.59	0.67
	2	0.03	0.46	0.19	0.02	0.09	0.01	0.09	0.19	0.07	0.32	0.29
	3	0.01	0.37	0.07	0.02	0.09	0.01	0.08	0.06	0.05	0.20	0.23
	4	0.01	0.28	0.06	0.01	0.07	0.01	0.07	0.10	0.04	0.18	0.20
	5	0.00	0.12	0.05	0.01	0.05	0.00	0.06	0.07	0.03	0.13	0.09
	6	0.00	0.08	0.05	0.00	0.05	0.00	0.05	0.06	0.03	0.10	0.09
	7	0.00	0.08	0.01	0.00	0.05	0.00	0.05	0.06	0.02	0.09	0.09
	8	0.00	0.05	0.01	0.00	0.04	0.00	0.05	0.05	0.01	0.04	0.08
Nails	1	0.01	0.43	0.19	0.03	0.02	0.02	0.02	0.13	0.07	0.24	0.34
	2	0.01	0.43	0.15	0.02	0.02	0.02	0.02	0.11	0.07	0.22	0.27
	3	0.00	0.15	0.08	0.02	0.01	0.01	0.01	0.08	0.04	0.15	0.22
	4	0.00	0.03	0.03	0.01	0.00	0.00	0.00	0.03	0.01	0.06	0.04

VITA

Susanna Hannah Sutherland was born in Spring City, Tennessee, in 1977. She received her B.A. in Environmental Studies, with a minor in Forestry at the University of Tennessee, Knoxville. She continued her education at the University of Tennessee, and received her M.S. from the College of Agriculture in the department of Biosystems Engineering and Environmental Science, with a concentration in Biosystems Engineering Technology in 2004. Susanna is anticipating a rewarding career in environmental science.